ASIAC

Report No. 779.1A
Revision 1

STATIC STRUCTURAL ANALYSIS OF THE LOREORS ELECTRONIC CONSOLE SUPPORT FRAME

19990518 044

September 1979

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AEROSPACE STRUCTURES
INFORMATION AND ANALYSIS CENTER

OPERATED FOR THE AIRFORCE FLIGHT DYNAMICS LABORATORY
BY ANAMET LABORATORIES, INC.

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Aerospace Structures Information and Analysis Center

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Aerospace Structures
Information and Analysis Center

Report No. 779.1A
Revision 1
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This report is a revision of Report No. 779.1A which contained some erroneous results due to improper loading application for the finite element analysis.

This report describes the static structural analysis used to verify the structural adequacy of the LOREORS Electronic Console Support Frame under crash loadings of a C-141 aircraft. The results of the analysis confirm that the support frame will satisfactorily withstand the loading conditions. This work was done by the Aerospace Structures Information and Analysis Center, which is operated for the Air Force Flight Dynamics Laboratory by Anamet Laboratories under Contract No. F33615-77-C-3046.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

This report documents a structural analysis performed by ASIAC personnel at the request of the Air Force to verify the structural integrity of the LOREORS Electronic Console Support Frame. The frame was analyzed for the crash loads as specified by the 4950th Flight Test Wing.

A schematic diagram of the support frame is shown in Figure 1. A detailed NASTRAN finite element model was constructed of the frame from dimensions given by the drawings listed in Appendix A. The finite element model was then subjected to the six independent crash loads to obtain the respective element deflections, forces and stresses.

This report further discusses the methodology of the analysis, including modeling assumptions and the interpretation of the NASTRAN results. Detailed calculations were performed for those areas of the structure not adequately analyzed by the finite element model. The results of the NASTRAN model and the detailed calculations are presented in Section III. The detailed calculations and calculations used to construct the model are both supplied in the appendices.

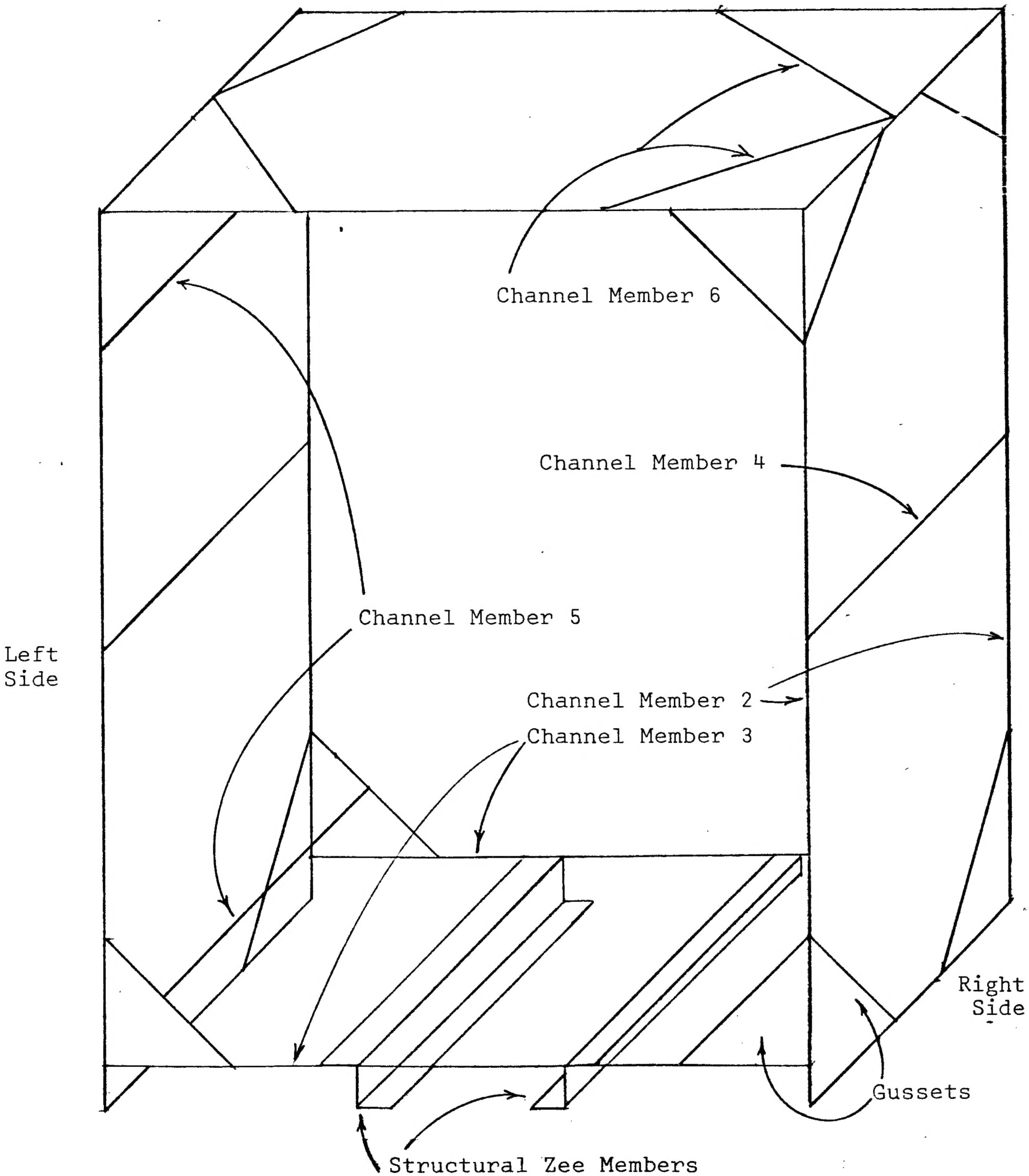


Figure 1 Schematic of Electronic Console Support Frame

II. TECHNICAL DISCUSSION

Static structural analysis of the LOREORS Electronic Console Support Frame was accomplished by using NASTRAN, a large scale finite element computer program, in conjunction with detailed hand calculation stress analyses. Detailed stress analysis was performed in all areas that lacked adequate definition due to the limitations of finite element modeling.

The support frame is constructed primarily of structural channel members with 0.375 in. thick gusset plates at the corners for reinforcement. It is an aluminum structure with the members joined by welds and designed to support a console cabinet weighing 1,450 lb. Vibration isolators are used to mount the console to the support frame.

The material properties used for the analysis are listed in Table 1. Since some discrepancy existed among the references for the properties, the predominant values were used.

As instructed by the 4950th Flight Test Wing, the crash loads used for the analysis were as follows:

9.0 g Fore (+x direction)
1.5 g Aft (-x direction)
1.5 g Side to Side (+z and -z directions)
6.0 g Down (-y direction)
3.0 g Up (+y direction)

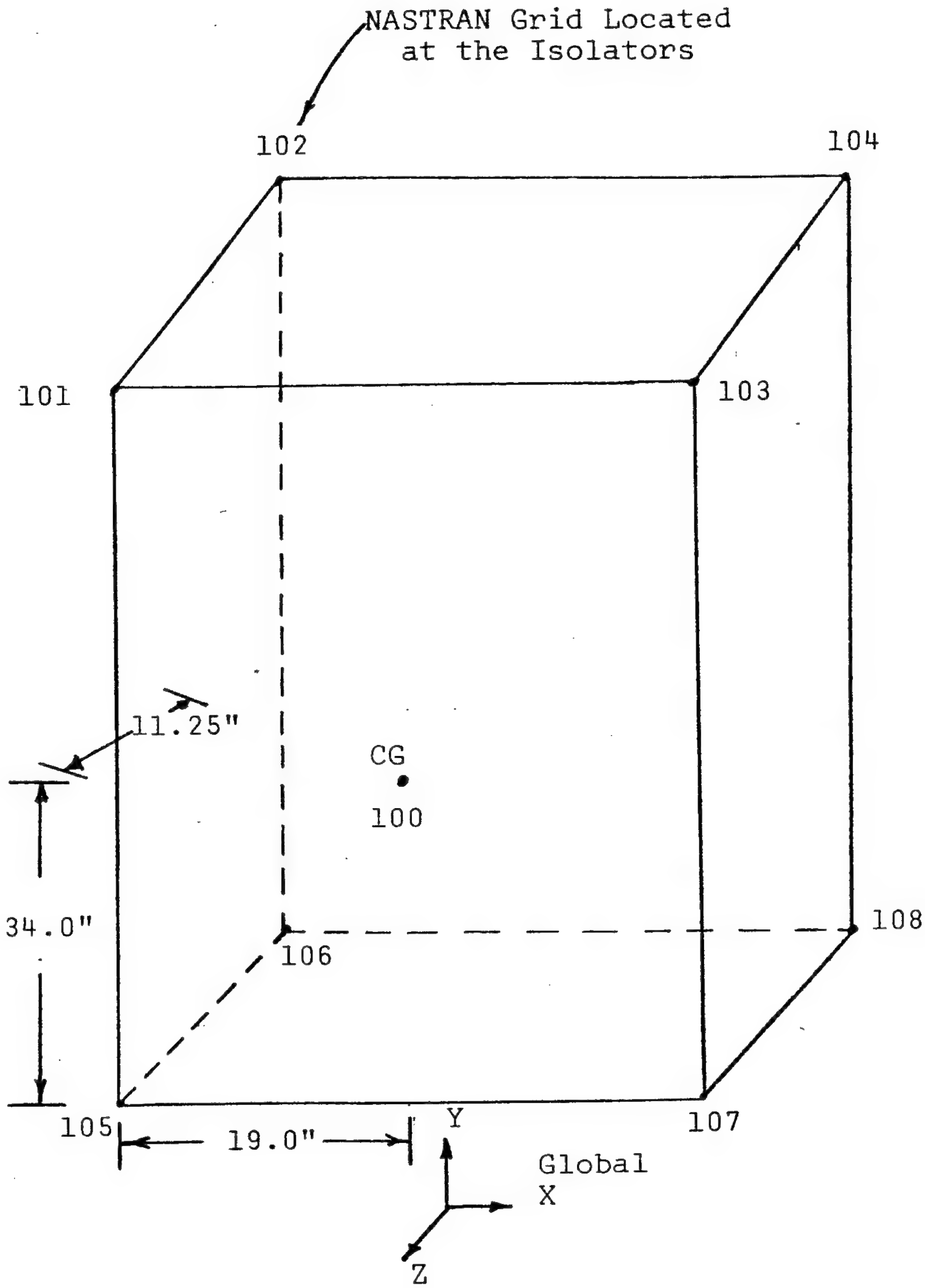
These constituted the six loading conditions used for the analysis with the respective applied global directions for the NASTRAN models as indicated above.

Initially, a separate model was constructed to represent the console and isolators in order to determine the console loads on the support frame. A concentrated weight of 1,450 lb. was located at the center of gravity for the console. Then, rigid elements were used to connect the weight to spring elements which simulated the isolators. Figure 2 is a schematic of the console model. Also, Figure 3 gives the load versus deflection characteristics of the isolators for axial loading. Using this

TABLE 1

MATERIAL PROPERTIES

Property	Al 6061-T6 QQ-A-200/8	Al 6061-T651 QQ-A-250/11	Welded 6061 With 5356 Filler Alloy
E($\times 10^6$ psi.)	10.4	10.4	-
G($\times 10^6$ psi.)	3.9	3.9	-
μ	0.33	0.33	-
ρ (lbf/in^3)	0.10	0.10	-
F_{tu} (psi.)	37,000	42,000	30,400
F_{ty} (psi.)	33,000	35,000	19,300
F_{cy} (psi.)	35,000	35,000	19,300
F_{su} (psi.)	27,000	27,000	60% F_{tu} = 18,240



Concentrated Weight of 1,450 lbs.
at Console CG

Figure 2 Schematic of Console Model

Isolator Spring Rate Calculation:

$$K = \frac{F}{\delta} = \frac{350 \text{ lb}}{0.20 \text{ in}} = 1750 \text{ lb/in}$$

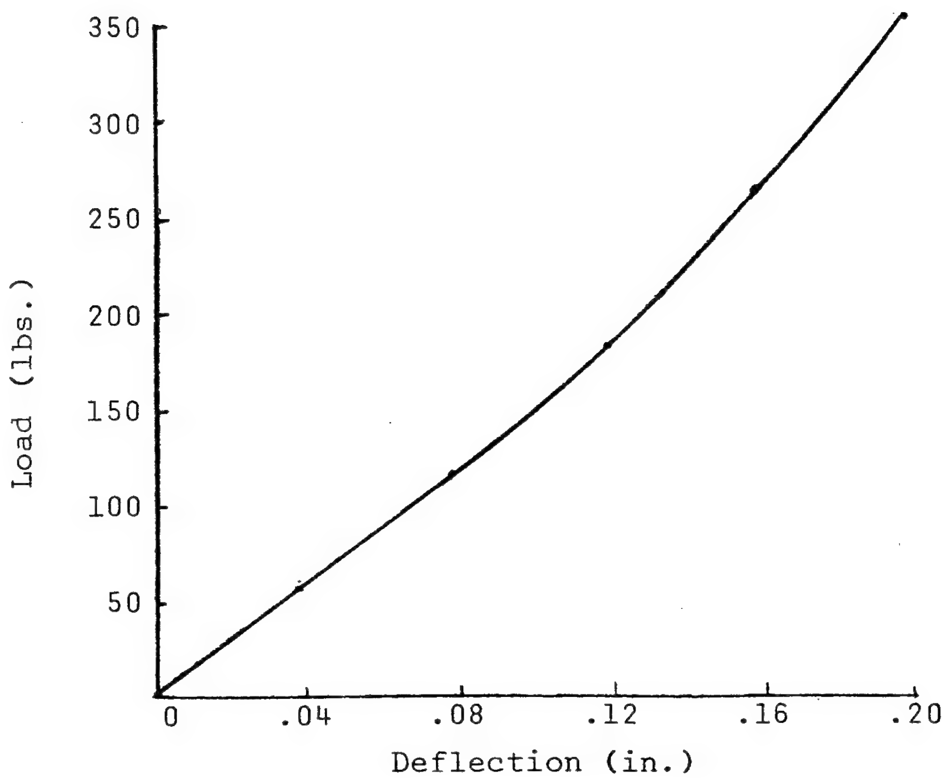


Figure 3 Load Versus Deflection for Model 507 Code 3 Isolator

curve, a spring rate of 1,750 lb/in. was calculated for the isolators. Since load versus deflection characteristics were not supplied for transverse shear, the spring rate for shear loading was assumed to be the same as the axial. Also, rotational spring rates for the isolators were calculated, assuming that they behaved isotropically. This model was then subjected to the six loading conditions to obtain the loads imposed by the console on the frame.

Several different spring rate values and spring configurations were analyzed. It was finally determined that the rotational spring components were insignificant, and did not need to be included. Therefore, the final console forces obtained were for springs only in the axial and the two transverse directions. Also, since the load versus deflection curve for the isolators was not linear, NASTRAN analyses were performed for spring rates calculated from different points on the curve. Finally, the spring rate for the end point on the curve was considered the best representation.

Next, the NASTRAN model of the support frame was developed according to the technical drawings. Since the support frame structure is symmetrical, the model was constructed for one-half of the structure, and reflective symmetry was used to evaluate the entire structure. Figure 4 is a schematic illustration of the symmetric half of the structure which was modeled. Actually, two generations of models were developed. The first model consisted primarily of offset bar elements with only the gussets modeled as plate elements. This model supplied a good representation of the overall load paths, yet lacked detailed definition at the corner weldment regions. The second generation model was a revision of the first by replacing the bar elements of some members with plate elements. The NASTRAN results for the first generation model indicated that the elements in the lower corners were higher stressed than those in the upper corners. Consequently, plate elements were used to model the connections between channel members 2, 3, and 5 and the gusset

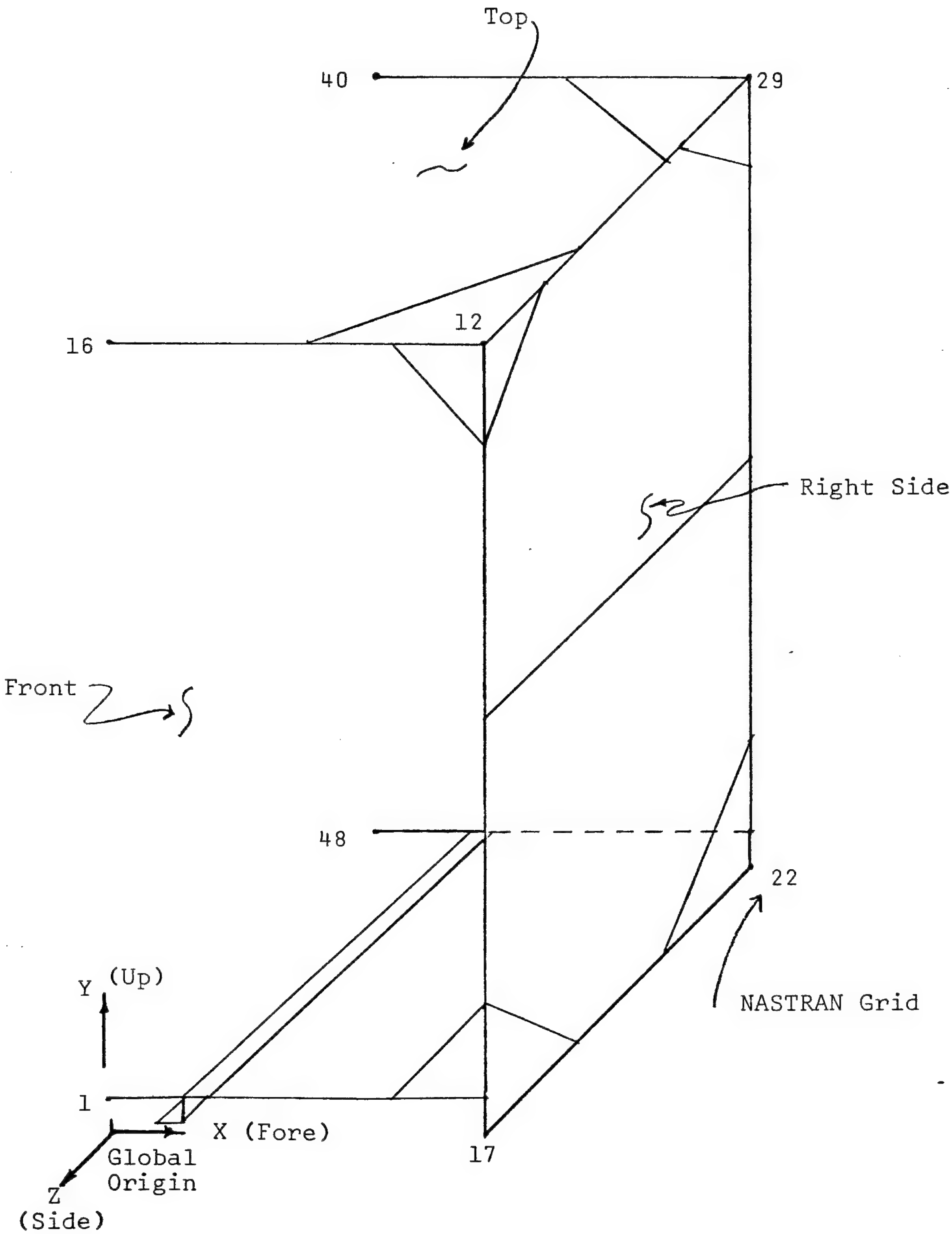


Figure 4 Schematic of the Model for Symmetric Right Half

plates at the lower corners. Figures 5 and 6 display these connections. The second generation model with this revision supplied results to adequately evaluate the weldment stresses for the lower corners. Only the results of the second generation model are being presented in this report. Figures 7 through 11 are NASTRAN plots which further illustrate the grid points and elements of the model. By using symmetry and anti-symmetry, the reaction loads from the console were correctly applied to the model. Grid points 32, 33, 53, and 54 represented the upper attachment locations of the isolators to the frame. Grid points 36, 37, 55, and 56 represented the lower attachment locations of the isolators to the frame. The reaction loads from the console were applied at these points.

Since the center of gravity for the console was not symmetric with respect to the support frame, two analyses were made with the support frame model. First, the model, as previously described for the right half of the structure, was executed with the applied console loads and six loading conditions. Next, by using symmetry and anti-symmetry, the loads were applied to the model to obtain the results for the left half of the structure. This method provided element displacements, forces and stresses for the entire support frame.

In order to simulate the boundary conditions for the attachment points on the base of the frame to the aircraft, grid points 41, 42, 62, and 63 were constrained from translation in any direction. These points were free to rotate, although in the actual structure some rotation will be restrained. By only constraining the translations, more conservative results will be obtained for those parts of the structure other than the base attachment areas. The model was also analyzed for the 1.5 g Side to Side, 9 g Fore, and 6 g Down loading conditions, with the attachment points fully constrained from translational and rotational displacements. This analysis using the fully constrained boundary conditions produced lower stresses, except for elements at the base attachment points. However, the stress

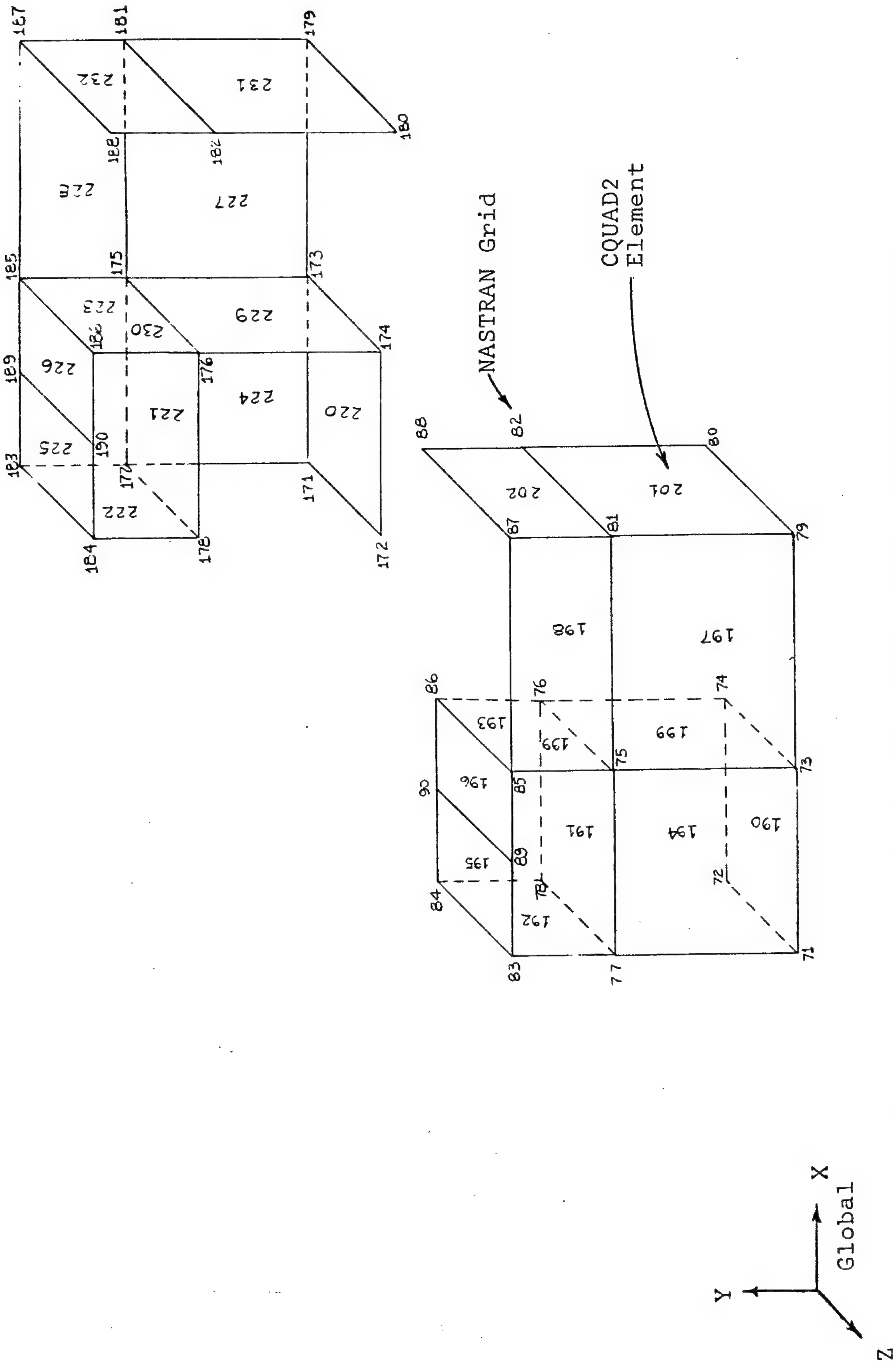


Figure 5 Lower Corner Structure of the Three Intersecting Channel Members, 2, 3 and 5

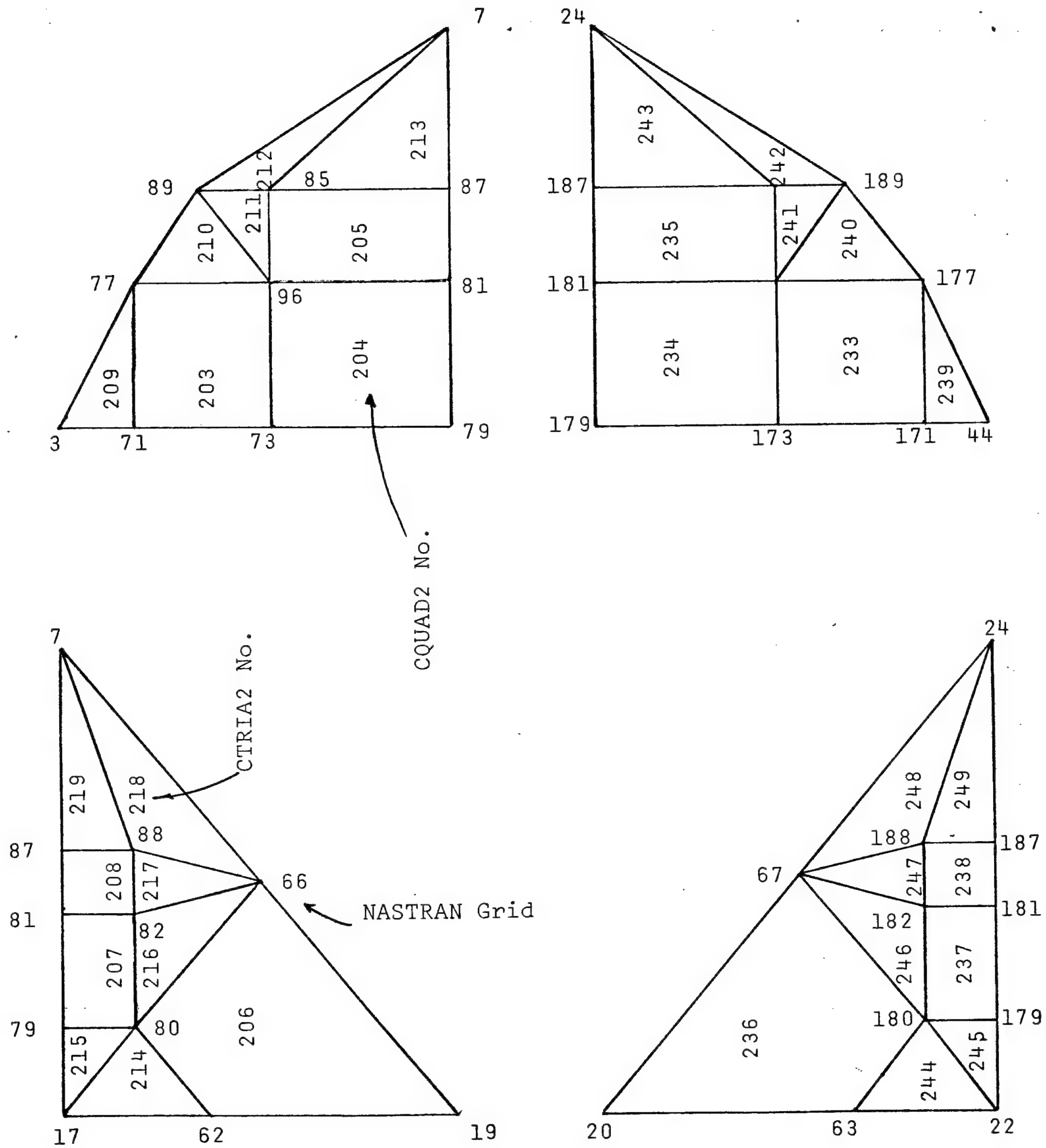


Figure 6 Drawing of NASTRAN Elements for Bottom Gusset Plates

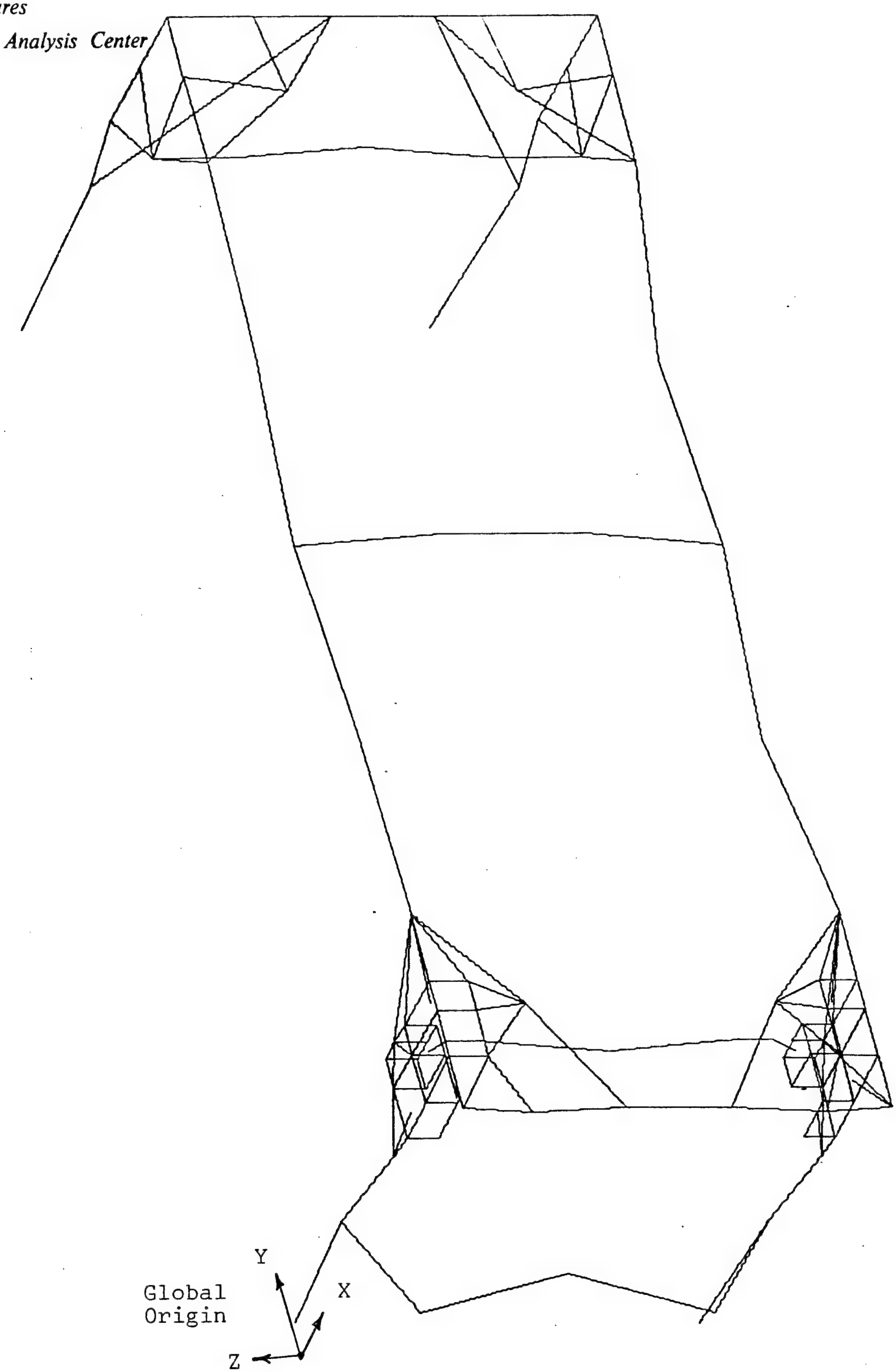


Figure 7 NASTRAN Plot of Complete Model

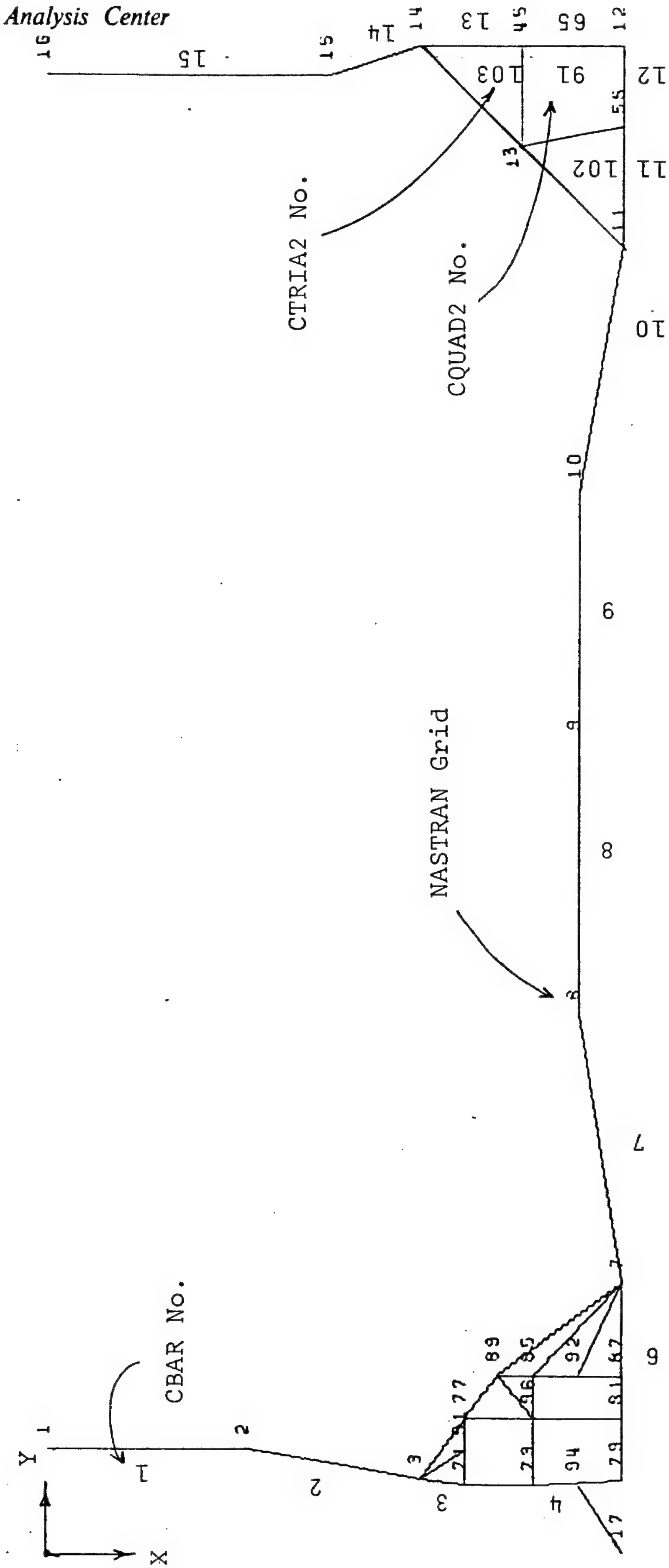


Figure 8 NASTRAN Plot of Front View at Z = 0

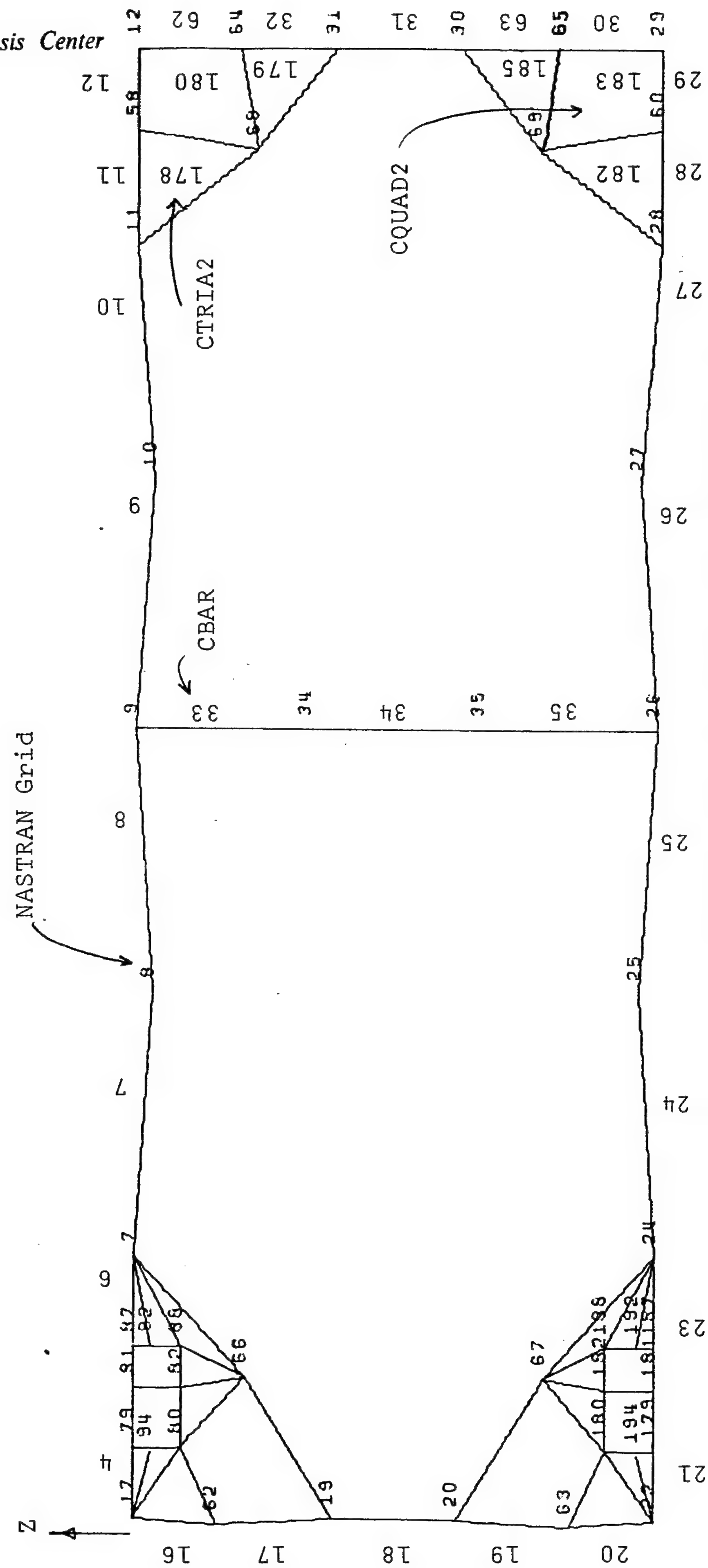


Figure 9 NASTRAN Plot of Right Side at X = 32.5

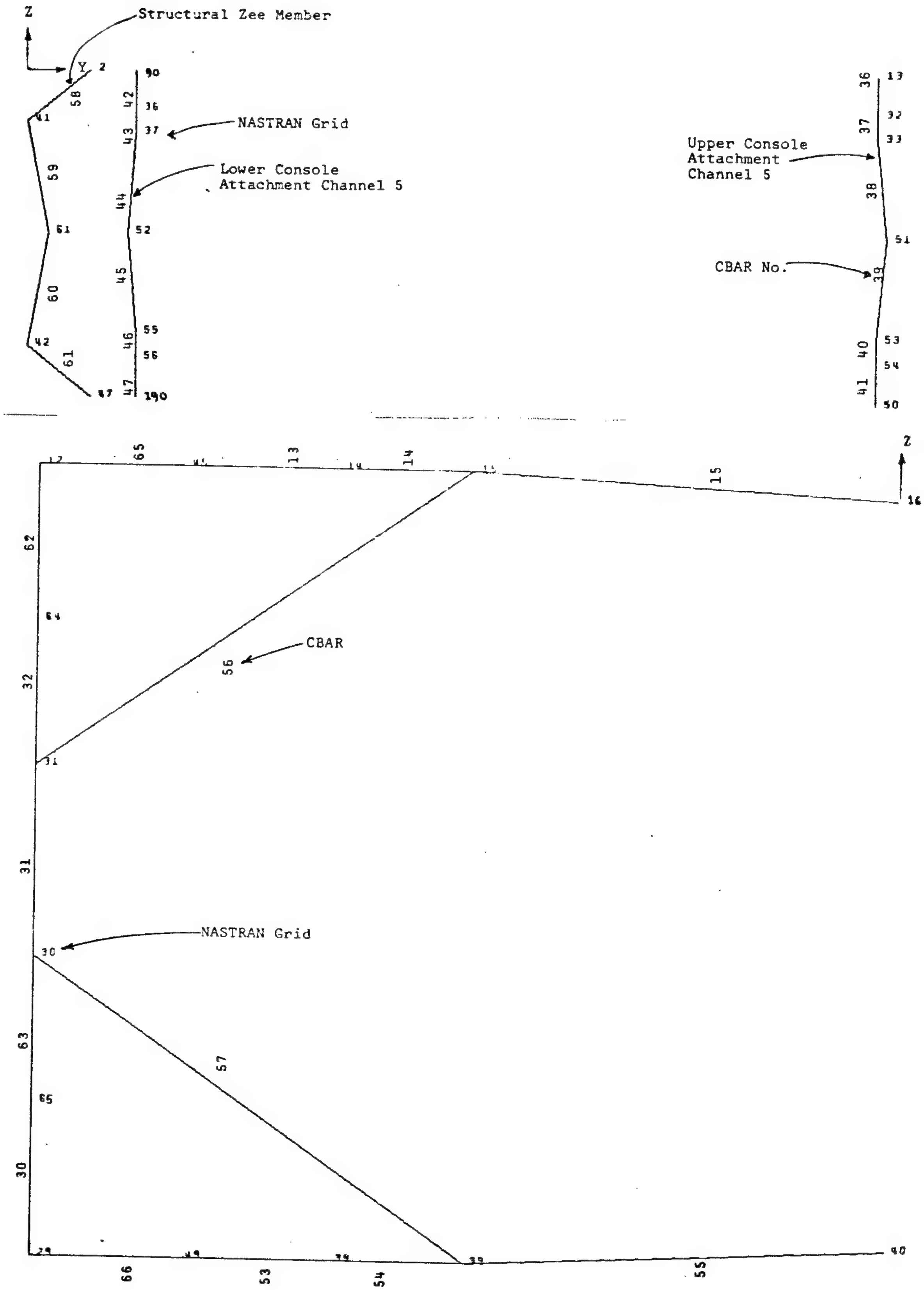


Figure 10   NASTRAN Plots of Upper and Lower Channels for Console Mounts, Base Zee and Top Structure

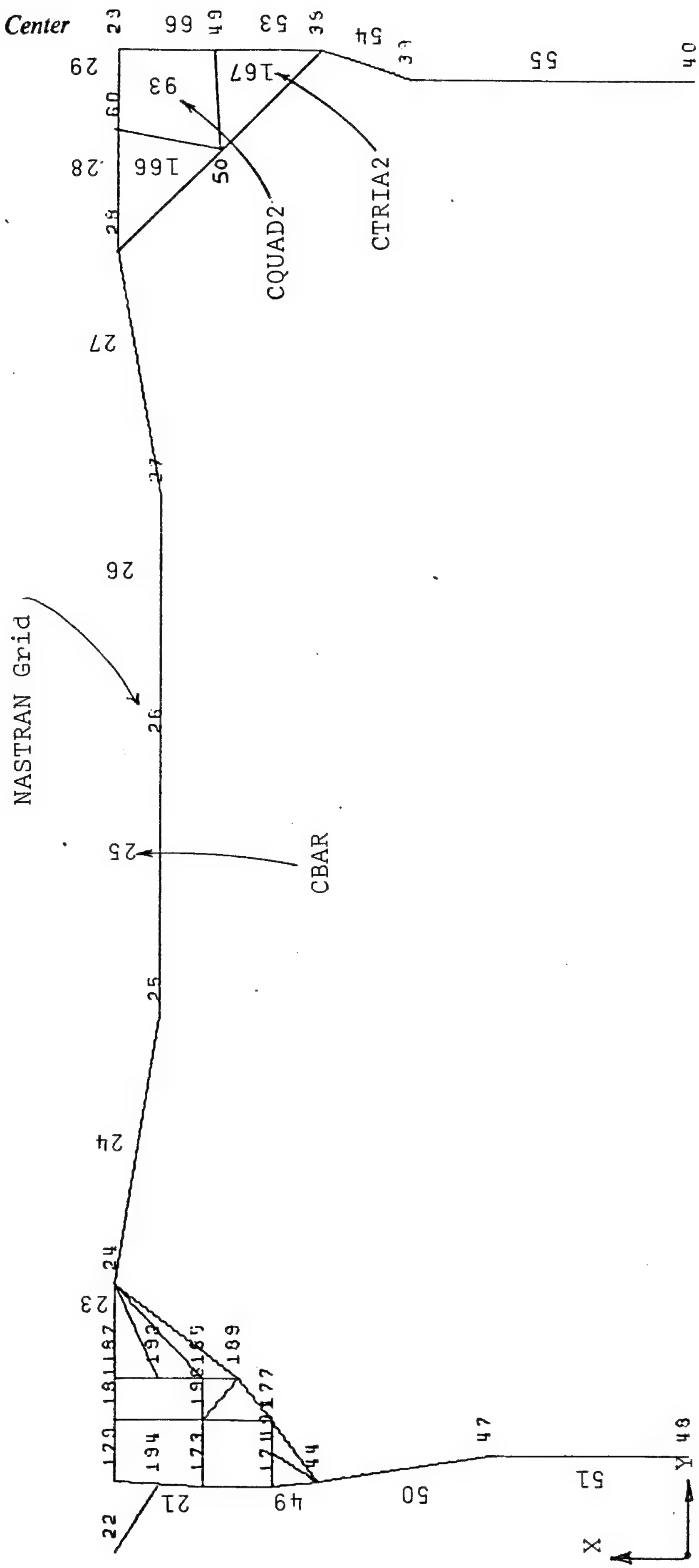


Figure 11 NASTRAN Plot of the Back View at Z = 30.0

increase at the attachment points was insignificant. Consequently, the results being presented were obtained by using the boundary conditions of the attachment points only constrained from translations.

Routine checks of the model showed the off diagonal to diagonal ratio and the epsilon values of the stiffness matrix to both be low, thus indicating a good numerical solution. Also, plotting was performed to verify the element connections. Figures 7 through 11, which illustrate the NASTRAN plots, show the bar elements in their unoffset positions. Offsets were used in the analysis to reposition the bar elements from the grid points to the elements centroid.

A printed output file of the input and output data created by NASTRAN is not included in this report due to its size. However, one copy of this printout has been sent to the 4950th Test Wing and an additional copy has been retained by ASIAC and is available upon request.

III. SUMMARY OF RESULTS

The structural adequacy for this support frame is verified by utilizing both the finite element technique and detailed stress analysis.

The finite element analysis uses NASTRAN to calculate internal moments and forces, as well as grid point displacements and element stresses. The internal forces and moments are used as applied loads for the detailed stress analysis.

The results of the NASTRAN stress analysis are shown in Table 2 for tension and in Table 3 for compression. The margins of safety for less than 5.00 are given in these tables, and are based on the yield strength of the material. The stress and force results for the evaluation of the left half of the support frame were the highest, and are the ones being presented and used for the detailed calculations. The results of the detailed calculations are given in Table 4. As indicated by the results in these tables, the margins of safety remained positive for the six loading conditions. The lowest margin of safety was 0.12, and resulted from the detailed analysis for the weldment stresses of the structural Zee member. The lowest margin of safety obtained from the NASTRAN output was 0.78 for element CBAR 2 in the 9 g fore loading condition. This element corresponds to the bottom horizontal support channel 3 at the front. The maximum stress obtained was 18,555 psi.

Appendix D contains calculations which verify static equilibrium of the entire support frame for the six loading conditions. The results of these calculations show that the summation of forces and moments for the left and right halves balance, thus demonstrating static equilibrium.

TABLE 2

NASTRAN RESULTS FOR THE MARGINS OF SAFETY
LESS THAN 5.0 AND THE CORRESPONDING TENSILE STRESS

Element Number	Loading	Maximum Stress (psi.)	Margin of Safety
CBAR2	9 g Fore	18,555	0.78
CBAR3	"	15,787	1.1
CBAR6	"	17,820	0.85
CBAR7	"	15,667	1.1
CBAR8	"	7,571	3.4
CBAR10	"	10,532	2.1
CBAR11	"	10,054	2.3
CBAR13	"	12,764	1.6
CBAR14	"	12,918	1.6
CBAR15	"	13,580	1.4
CBAR18	"	6,272	4.3
CBAR19	"	6,250	4.3
CBAR23	"	16,513	1.0
CBAR24	"	14,728	1.3
CBAR25	"	7,298	3.5
CBAR27	"	9,947	2.3
CBAR28	"	8,204	3.0
CBAR49	"	15,189	1.2
CBAR50	"	17,710	0.86
CBAR53	"	12,502	1.6
CBAR54	"	12,677	1.6
CBAR55	"	11,493	1.9
CBAR58	"	13,917	1.4
CBAR61	"	13,156	1.5
CBAR37	6 g Down	6,161	4.4
CBAR40	"	6,113	4.4

TABLE 3

NASTRAN RESULTS FOR MARGINS OF SAFETY
LESS THAN 5.0
AND THE CORRESPONDING COMPRESSIVE STRESS

Element Number	Loading	Maximum Stress (psi.)	Margin of Safety
CBAR2	9 g Fore	12,581	1.8
CBAR3	"	7,818	3.5
CBAR6	"	16,622	1.1
CBAR7	"	18,035	0.94
CBAR8	"	8,948	2.9
CBAR10	"	11,666	2.0
CBAR11	"	12,658	1.8
CBAR12	"	6,409	4.5
CBAR13	"	13,966	1.5
CBAR14	"	13,352	1.6
CBAR15	"	12,769	1.7
CBAR23	"	14,790	1.4
CBAR24	"	16,178	1.2
CBAR25	"	8,930	2.9
CBAR27	"	11,827	2.0
CBAR28	"	11,511	2.0
CBAR29	"	6,426	4.4
CBAR49	"	7,663	3.6
CBAR50	"	12,050	1.9
CBAR53	"	13,594	1.6
CBAR54	"	12,966	1.7
CBAR55	"	11,489	2.0
CBAR58	"	14,090	1.5
CBAR59	"	6,489	4.4
CBAR60	"	6,029	4.8
CBAR61	"	13,295	1.6
CBAR37	6 g Down	7,970	3.4
CBAR38	"	6,850	4.1
CBAR39	"	6,834	4.1
CBAR40	"	7,814	3.5

TABLE 4

SUMMARY OF DETAILED CALCULATION
STRESSES AND MARGINS OF SAFETY

Location	Loading	Maximum Stress (psi.)	Margins of Safety
Weldment of cross member Channel 4 to vertical Channel 2	Combined: 9 g Fore, 6 g Down, 1.5 g Side	10,097	0.91
Weldment of Zee member to Channel member No. 3	9 g Fore	17,289	0.12
Beam column buckling of vertical Channel No. 2	Combined: 9 g Fore, 6 g Down, 1.5 g Side	-	1.2
Isolator elastomer	Combined: 9 g Fore, 6 g Down, 1.5 g Side	2,712	0.5

Tables 5 and 6 summarize the console attachment reactions and the isolator deflections. The attachment reactions were obtained from the rigid console model, and were the loads applied at the attachment points on the support frame. The isolator deflections are the relative displacements of that part of the isolator attached to the console to that part of the isolator attached to the support frame. Only the deflections for the 9 g Fore and the 6 g Down loading conditions are given in Table 6. These are the only deflections needed to check for bottoming out of the isolators. According to the detailed calculations in Appendix C, the isolators may bottom out for the 9 g Fore loading condition. The deflection value used for the calculations was from the NASTRAN results. As discussed previously, the spring rates used are from the end point of the load versus deflection curve in Figure 3. Further inspection of this curve shows that the spring rate should increase as the load increases. Consequently, the spring rate for the isolator load of the 9 g Fore loading condition will be greater than the one used in the NASTRAN analysis. Therefore, the deflection is expected to be lower so that bottoming out will not occur. If a spring rate of 2,023 lb/in. was assumed, bottoming out would not occur. This spring rate is reasonable considering Figure 3.

The detailed stress calculations in Appendix C are used to examine the critical weldment areas of the structure and the susceptibility to buckling of the vertical channel beam column. The results of the detailed calculations demonstrated positive margins of safety for the weldment stresses and for column buckling stability. Also, the detailed stress calculations of the isolators yielded positive margins of safety.

TABLE 5

CONSOLE REACTION FORCES

Console Grid	X Direction (lbs.)	Y Direction (lbs.)	Z Direction (lbs.)
	For 1.5 g +Z Direction Loading		
101	18.45	0.13	317.33
102	-18.45	-0.13	317.33
103	18.45	0.13	225.54
104	-18.45	-0.13	225.54
105	18.45	0.13	318.21
106	-18.45	-0.13	318.21
107	18.45	0.13	226.42
108	-18.45	-0.13	226.42
	For 1.5 g -Z Direction Loading		
101	-18.45	-0.13	-317.33
102	18.45	0.13	-317.33
103	-18.45	-0.13	-225.54
104	18.45	0.13	-225.54
105	-18.45	-0.13	-318.21
106	18.45	0.13	-318.21
107	-18.45	-0.13	-226.42
108	18.45	0.13	-226.42
	For 9.0 g +X Direction Loading		
101	1,668.15	-1.38	96.38
102	1,590.67	-1.38	96.38
103	1,668.15	1.38	-96.38
104	1,590.67	1.38	-96.38
105	1,671.83	-1.38	96.38
106	1,594.35	-1.38	96.38
107	1,671.83	1.38	-96.38
108	1,594.35	1.38	-96.38
	For 1.5 g -X Direction Loading		
101	-278.02	0.23	-16.06
102	-265.11	0.23	-16.06
103	-278.02	-0.23	16.06
104	-265.11	-0.23	16.06
105	-278.64	0.23	-16.06
106	-265.73	0.23	-16.06
107	-278.64	-0.23	16.06
108	-265.73	-0.23	16.06

TABLE 5
(Continued)

Console Grid	X Direction (lbs.)	Y Direction (lbs.)	Z Direction (lbs.)
	For 6 g -Y Direction Loading		
101	-102.30	-1,179.51	51.24
102	-102.30	-1,148.67	51.24
103	-102.30	-1,026.33	51.24
104	-102.30	-995.49	51.24
105	102.30	-1,179.51	-51.24
106	102.30	-1,148.67	-51.24
107	102.30	-1,026.33	-51.24
108	102.30	-995.49	-51.24
	For 3 g +Y Direction Loading		
101	51.15	589.76	-25.62
102	51.15	574.34	-25.62
103	51.15	513.16	-25.62
104	51.15	497.74	-25.62
105	-51.15	589.76	25.62
106	-51.15	574.34	25.62
107	-51.15	513.16	25.62
108	-51.15	497.74	25.62

TABLE 6

ISOLATOR RELATIVE DISPLACEMENTS AT
9 G FORE AND 6 G DOWN LOADING CONDITIONS

	Grid	X (in.)	Y (in.)	Z (in.)
9 g Fore				
	101	0.01	0.03	0.02
	102	0.01	0.03	0.02
	103	0.02	0.03	0.02
	104	0.01	0.03	0.02
	105	0.87	0.02	0.05
	106	0.83	0.02	0.05
	107	0.87	0.02	0.05
	108	0.83	0.02	0.05
6 g Down				
	101	0.01	0.61	0.01
	102	0.01	0.60	0.01
	103	0.02	0.53	0.01
	104	0.02	0.51	0.01
	105	0.05	0.64	0.03
	106	0.05	0.56	0.03
	107	0.05	0.55	0.03
	108	0.05	0.54	0.03

IV. CONCLUSIONS

The results from the NASTRAN model and the detailed calculations satisfactorily ascertain the structural capability of the LOREORS Electronic Support Frame for the previously described loading conditions.

Briefly, the lowest margins of safety and their corresponding locations are as follows:

Channel No. 3 for base structure near structural Zee member at left side on the front	+0.78
Vertical Channel No. 2 at left side on front	+0.85
Channel No. 3 for base structure near structural Zee member at left side on the back	+0.86
Weld between Channel No. 4 and Channel No. 2 at left side on the front	+0.91
Weld between structural Zee and Channel No. 3 at left side on the back	+0.12
Column buckling for vertical Channel No. 2	+1.2
Isolator elastomer stress	+0.5

Figure 1 clarifies the locations referred to here.

In conclusion, all the results verify that the support frame will maintain its structural integrity and be able to withstand the specified loading conditions.

APPENDIX A

TABULATION OF TECHNICAL DRAWINGS FOR LOREORS ELECTRONIC CONSOLE SUPPORT FRAME

TECHNICAL DRAWINGS

Description	Fairchild Imaging Systems Drawing Number
Frame Weldment, Console Support	1289-559 sheet 1
Frame Weldment, Console Support	1289-559 sheet 2
Cabinet Assembly - 2 Bay RFI Shielded	1285-519 sheet 3

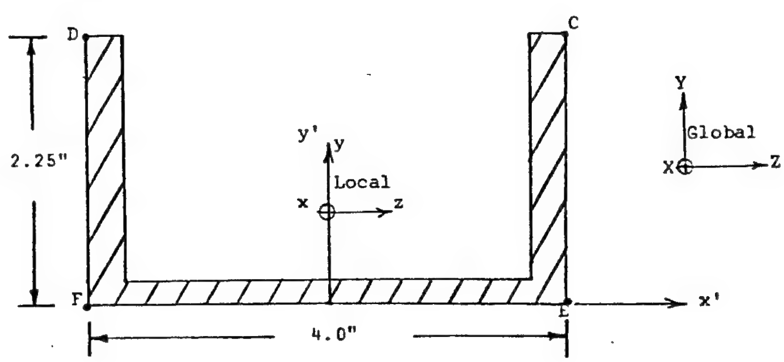
APPENDIX B

PBAR PROPERTY CALCULATIONS

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 1
2
3

DESCRIPTION: Lower front frame channel 3
4 x 2.25, 0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
1	0.0	0.0	0.0	0.0	0.0	-0.783
2	0.0	0.0	-0.783	0.0	1.62	-0.783
3	0.0	1.62	-0.783	0.0	1.62	-0.783

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.67$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

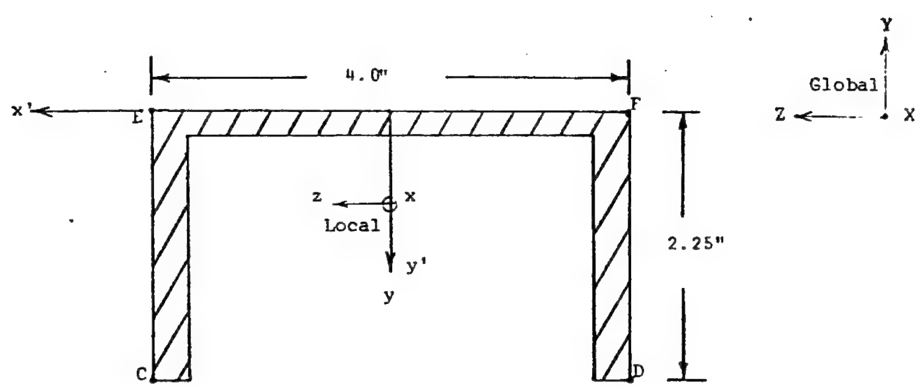
```
                                  INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
 TYPE   DUM       B          H          B1         H1         X          Y          ALF
 RECT 0.00    4.00000    2.25000    0.00000    0.00000    0.00000    0,00000    0.00000
 RECT-1.00    3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.     AREA        XC         YC         IX         IY         IXY        K
  1   9.00000    0.00000    1.12500    3.79688   12.00000    0.00000   15.18750
  2  -7.04520    0.00000    1.22000   -2.49142   -6.86696    0.00000   -4.96567
```

```
TOTAL AREA=                     .195E+01
X CENTROID DISTANCE=         0.
Y CENTROID DISTANCE=            .783E+00
IX (ABOUT CENTROID)=            .101E+01
IY (ABOUT CENTROID)=            .513E+01
IXY (ABOUT CENTROID)=        0.
IMAX=                           .513E+01
IMIN=                           .101E+01
ALPHA=                         -.180E+03
TORSIONAL CONSTANT, K=          .522E+01
IX (ABOUT INPUT AXIS)=          .221E+01                  Y= 0.
IY (ABOUT INPUT AXIS)=          .513E+01                  X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 13
14
15

DESCRIPTION: Upper front frame channel 3
4 x 2.25, 0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
13	0.0	-1.62	-0.783	0.0	-1.62	-0.783
14	0.0	-1.62	-0.783	0.0	0.0	-0.783
15	0.0	0.0	-0.783	0.0	0.0	-0.783

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.67$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

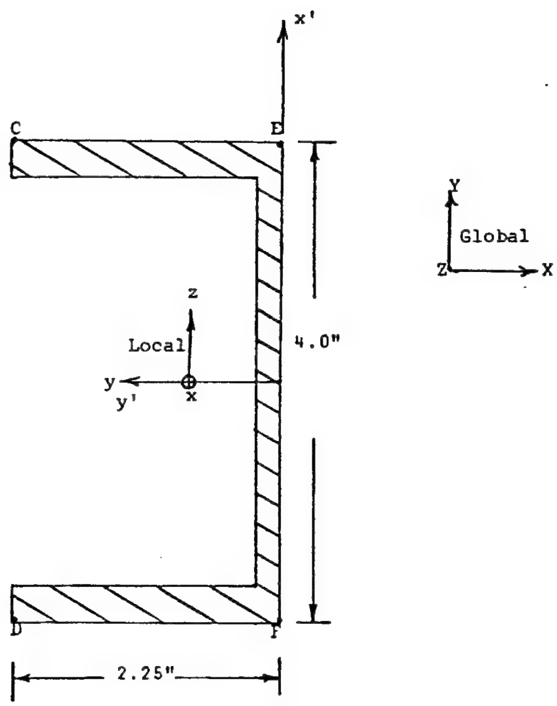
```
                                INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
 TYPE  DUM       B          H          B1         H1         X          Y          ALF
 RECT  0.00   4.00000    2.25000    0.00000    0.00000    0.00000    0.00000    0.00000
 RECT -1.00   3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.    AREA        XC         YC         IX         IY          IXY        K
  1  9.00000    0.00000    1.12500    3.79688   12.00000    0.00000   15.18750
  2 -7.04520    0.00000    1.22000   -2.49142   -6.86696    0.00000   -9.96567
```

```
TOTAL AREA=                    .195E+01
X CENTROID DISTANCE=          0.
Y CENTROID DISTANCE=           .783E+00
IX (ABOUT CENTROID)=           .101E+01
IY (ABOUT CENTROID)=           .513E+01
IXY (ABOUT CENTROID)=         0.
IMAX=                          .513E+01
IMIN=                          .101E+01
ALPHA=                        -.180E+03
TORSIONAL CONSTANT, K=         .522E+01
IX (ABOUT INPUT AXIS)=         .221E+01            Y= 0.
IY (ABOUT INPUT AXIS)=         .513E+01            X= 0.
IXY (ABOUT INPUT AXIS)=       0.

TORSIONAL CONSTANT BASED ON SUM
      NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 33
34
35

DESCRIPTION: Cross brace, channel 4,
4 x 2.25, 0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
33	1.40	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.67$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

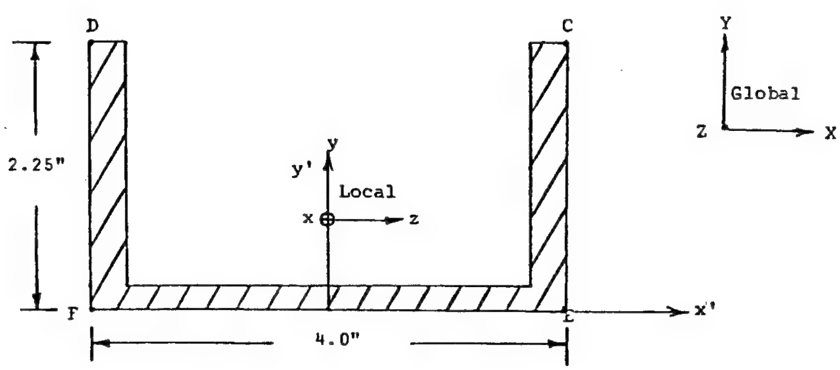
```
INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
 TYPE   DUM      B          H          B1         H1         X          Y          ALF
 RECT 0.00   4.00000    2.25000    0.00000    0.00000    0.00000    0.00000    0.00000
 RECT-1.00   3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.    AREA        XC          YC          IX          IY          IXY         K
  1   9.00000    0.00000    1.12500     3.79688   12.00000    0.00000   15.18750
  2  -7.04520    0.00000    1.22000    -2.49142   -6.86696    0.00000   -9.96567
```

```
TOTAL AREA=                    .195E+01
X CENTROID DISTANCE=          0.
Y CENTROID DISTANCE=           .783E+00
IX (ABOUT CENTROID)=           .101E+01
IY (ABOUT CENTROID)=           .513E+01
IXY (ABOUT CENTROID)=         0.
IMAX=                          .513E+01
IMIN=                          .101E+01
ALPHA=                        -.180E+03
TORSIONAL CONSTANT, K=         .522E+01
IX (ABOUT INPUT AXIS)=         .221E+01              Y= 0.
IY (ABOUT INPUT AXIS)=         .513E+01              X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 36
38
39
41

DESCRIPTION: Upper console support channel 5
4 x 2.25, 0.19 web, 0.29 flange, Al6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
36,41	0.0	0.783	0.0	0.0	0.783	0.0
38	0.0	0.783	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.783	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.68$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

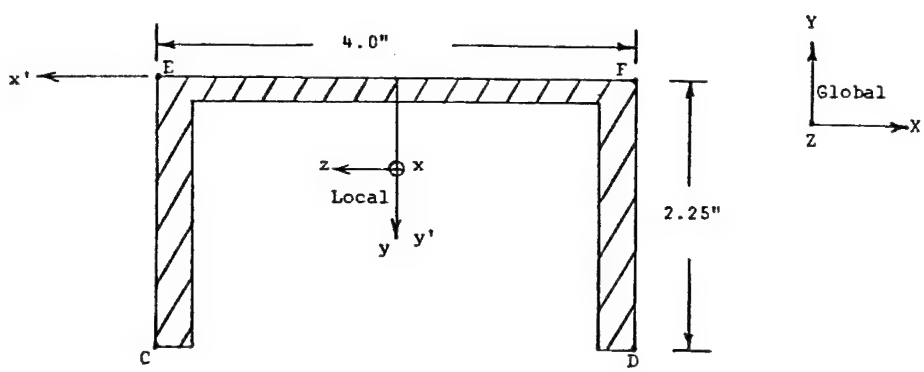
```
                                  INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
 TYPE  DUM      B          H          B1         H1         X          Y          ALF
 RECT 0.00  4.00000    2.25000    0.00000    0.00000    0.00000    0.00000    0.00000
 RECT-1.00  3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.    AREA         XC         YC         IX        IY          IXY        K
  1  9.00000    0.00000    1.12500   3.79688  12.00000    0.00000   15.16750
  2 -7.04520    0.00000    1.22000  -2.49142  -6.86696    0.00000   -9.96567
```

```
TOTAL AREA=                      .195E+01
X CENTROID DISTANCE=           0.
Y CENTROID DISTANCE=             .783E+00
IX (ABOUT CENTROID)=             .101E+01
IY (ABOUT CENTROID)=             .513E+01
IXY (ABOUT CENTROID)=          0.
IMAX=                            .513E+01
IMIN=                            .101E+01
ALPHA=                          -.180E+03
TORSIONAL CONSTANT, K=           .522E+01
IX (ABOUT INPUT AXIS)=           .221E+01                Y= 0.
IY (ABOUT INPUT AXIS)=           .513E+01                X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 42
44
45
47

DESCRIPTION: Lower console support, channel 5
4 x 2.25, 0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
42	0.0	0.0	0.0	0.0	0.0	-0.783
44	0.0	-0.783	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	0.0	-0.783	0.0
47	0.0	-0.783	0.0	0.0	0.0	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.67$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

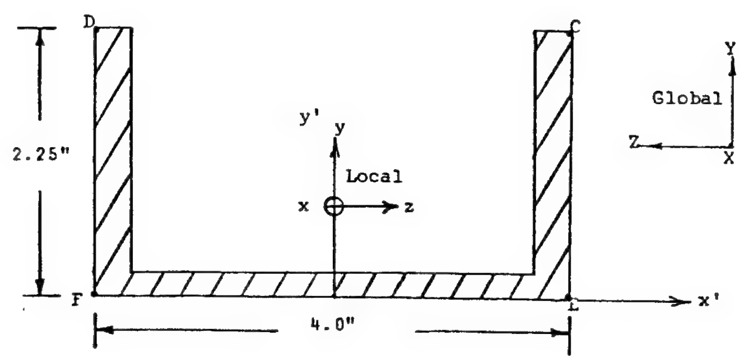
```
INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
 TYPE  DUM      B          H          B1         H1         X          Y          ALF
 RECT 0.00  4.00000    2.25000    0.00000    0.00000    0.00000    0.00000    0.00000
 RECT-1.00  3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.     AREA          XC         YC          IX         IY          IXY        K
  1  9.00000      0.00000    1.12500    3.79688   12.00000     0.00000   15.16750
  2 -7.04520      0.00000    1.22000   -2.49142   -6.86696     0.00000   -9.96567
```

```
TOTAL AREA=                  .195E+01
X CENTROID DISTANCE=        0.
Y CENTROID DISTANCE=         .783E+00
IX (ABOUT CENTROID)=         .101E+01
IY (ABOUT CENTROID)=         .513E+01
IXY (ABOUT CENTROID)=       0.
IMAX=                        .513E+01
IMIN=                        .101E+01
ALPHA=                      -.180E+03
TORSIONAL CONSTANT, K=       .522E+01
IX (ABOUT INPUT AXIS)=       .221E+01          Y= 0.
IY (ABOUT INPUT AXIS)=       .513E+01          X= 0.
IXY (ABOUT INPUT AXIS)=     0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 49
50
51

DESCRIPTION: Lower back frame channel 3
4 x 2.25, 0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
49	0.0	1.62	0.783	0.0	1.62	0.783
50	0.0	1.62	0.783	0.0	0.0	0.783
51	0.0	0.0	0.783	0.0	0.0	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.67$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

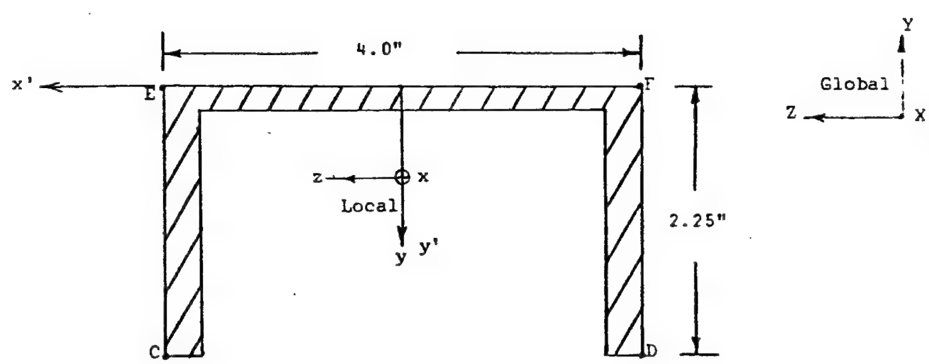
```
INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
 TYPE  DUM      B          H          B1         H1         X          Y          ALF
 RECT 0.00   4.00000    2.25000    0.00000    0.00000    0.00000    0,00000    0.00000
 RECT-1.00   3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.     AREA          XC          YC          IX         IY          IXY        K
  1   9.00000     0,00000     1.12500     3.79688   12.00000     0.00000   15.18750
  2  -7.04520     0.00000     1.22000    -2.49142   -6.86696     0.00000   -9.96567
```

```
TOTAL AREA=                   .195E+01
X CENTROID DISTANCE=        0.
Y CENTROID DISTANCE=          .783E+00
IX (ABOUT CENTROID)=          .101E+01
IY (ABOUT CENTROID)=          .513E+01
IXY (ABOUT CENTROID)=       0.
IMAX=                         .513E+01
IMIN=                         .101E+01
ALPHA=                       -.180E+03
TORSIONAL CONSTANT, K=        .522E+01
IX (ABOUT INPUT AXIS)=        .221E+01             Y= 0.
IY (ABOUT INPUT AXIS)=        .513E+01             X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 53
54
55

DESCRIPTION: Upper back frame channel 3
4 x 2.25, .19 web, .29 flange, Al 6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
53	0.0	-1.62	0.783	0.0	-1.62	0.783
54	0.0	-1.62	0.783	0.0	0.0	0.783
55	0.0	0.0	0.783	0.0	0.0	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.67$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

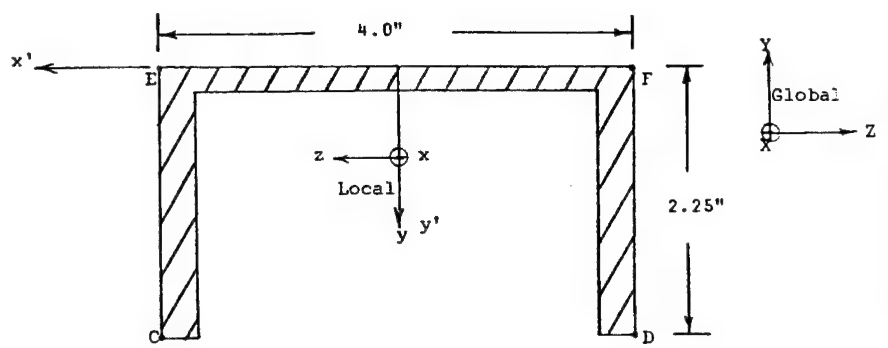
```
                                   INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
 TYPE  DUM      B          H          B1         H1         X          Y          ALF
 RECT 0.00  4.00000    2.25000    0.00000    0.00000    0.00000    0.00000    0.00000
 RECT-1.00  3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.    AREA        XC         YC         IX         IY         IXY        K
  1  9.00000    0.00000    1.12500    3.79688   12.00000    0.00000   15.18750
  2 -7.04520    0.00000    1.22000   -2.49142   -6.86696    0.00000   -9.96567
```

```
TOTAL AREA=                  .195E+01
X CENTROID DISTANCE=        0.
Y CENTROID DISTANCE=         .783E+00
IX (ABOUT CENTROID)=         .101E+01
IY (ABOUT CENTROID)=         .513E+01
IXY (ABOUT CENTROID)=       0.
IMAX=                        .513E+01
IMIN=                        .101E+01
ALPHA=                      -.180E+03
TORSIONAL CONSTANT, K=       .522E+01
IX (ABOUT INPUT AXIS)=       .221E+01            Y= 0.
IY (ABOUT INPUT AXIS)=       .513E+01            X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 1

ELEMENT NUMBERS: 56
57

DESCRIPTION: Diagonal cross brace at the top, channel 6
4 x 2.25, 0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 1 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.467	2.0
D	1.467	-2.0
E	-0.783	2.0
F	-0.783	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
56	0.0	0.930	0.0	-5.0	-0.40	-0.82
57	0.0	0.930	0.0	-5.0	-0.40	0.82

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.95} = 0.67$$

$$K_2 = \frac{4(0.19)}{1.95} = 0.39$$

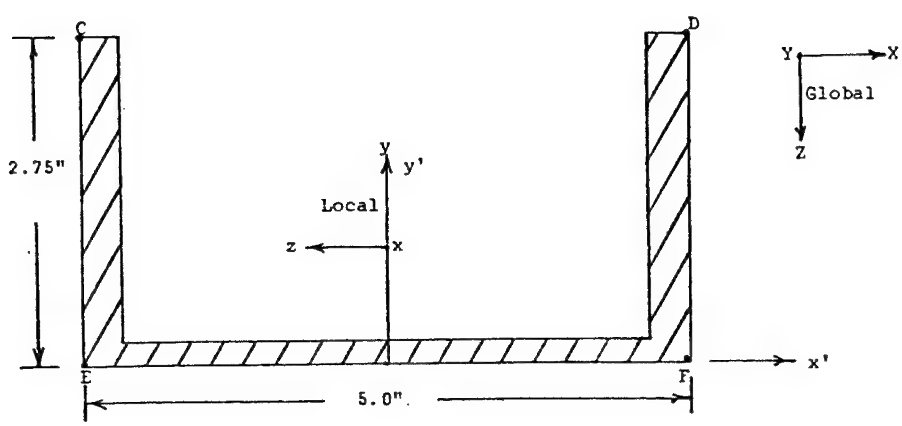
```
                              INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 1

INPUT
TYPE  DUM      B         H         B1        H1        X         Y         ALF
RECT 0.00  4.00000   2.25000   0.00000   0.00000   0.00000   0.00000   0.00000
RECT-1.00  3.42000   2.06000   0.00000   0.00000   0.00000    .19000   0.00000

OUTPUT
NO.    AREA        XC        YC         IX        IY         IXY        K
 1  9.00000    0.00000   1.12500   3.79688  12.00000    0.00000  15.18750
 2 -7.04520    0.00000   1.22000  -2.49142  -6.86696    0.00000  -9.96567
```

```
TOTAL AREA=                  .195E+01
X CENTROID DISTANCE=        0.
Y CENTROID DISTANCE=         .783E+00
IX (ABOUT CENTROID)=         .101E+01
IY (ABOUT CENTROID)=         .513E+01
IXY (ABOUT CENTROID)=       0.
IMAX=                        .513E+01
IMIN=                        .101E+01
ALPHA=                      -.180E+03
TORSIONAL CONSTANT, K=       .522E+01
IX (ABOUT INPUT AXIS)=       .221E+01             Y= 0.
IY (ABOUT INPUT AXIS)=       .513E+01             X= 0.
IXY (ABOUT INPUT AXIS)=    0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 2

ELEMENT NUMBERS: 4
6
7
8
9
10
11
12

DESCRIPTION: Vertical channel 2 at the front
5 x 2.75, 0.19 web, 0.32 flange, Al 6061-T6



PROPERTY NUMBER: 2(continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.785	2.5
D	1.785	-2.5
E	-0.965	2.5
F	-0.965	-2.5

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
4	-2.50	-0.38	-0.965	0.0	0.0	0.0
6	0.0	0.0	0.0	-2.50	0.0	-0.965
7	-2.50	0.0	-0.965	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	-0.965
9	0.0	0.0	-0.965	0.0	0.0	0.0
10	0.0	0.0	0.0	-2.50	0.0	-0.965
11	-2.50	0.0	-0.965	-2.50	0.0	-0.965
12	-2.50	0.0	-0.965	-2.50	0.0	-0.965

SHEAR FACTORS

$$K_1 = \frac{2(2.75)(0.32)}{2.59} = 0.68$$

$$K_2 = \frac{5(0.19)}{2.59} = 0.37$$

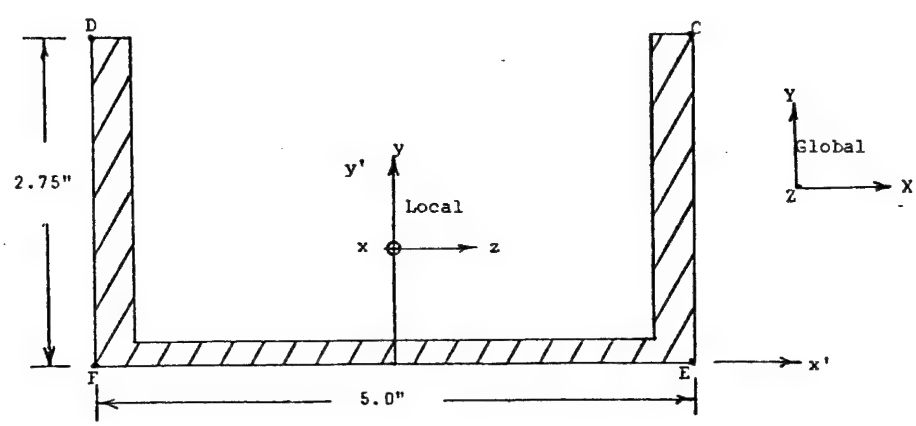
```
                                   INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 2

INPUT
TYPE  DUM      B          H          B1         H1         X          Y          ALF
RECT 0.00  5.00000    2.75000    0.00000    0.00000    0.00000    0.00000    0.00000
RECT-1.00  4.36000    2.56000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
NO.    AREA        XC         YC         IX        IY         IXY        K
 1 13.75000    0.00000    1.37500    8.66536  28.64583    0.00000  34.68146
 2-11.16160    0.00000    1.47000   -6.09572 -17.68146    0.00000 -24.38289
```

```
TOTAL AREA=                    .259E+01
X CENTROID DISTANCE=          0.
Y CENTROID DISTANCE=           .965E+00
IX (ABOUT CENTROID)=           .203E+01
IY (ABOUT CENTROID)=           .110E+02
IXY (ABOUT CENTROID)=         0.
IMAX=                          .110E+02
IMIN=                          .203E+01
ALPHA=                        -.180E+03
TORSIONAL CONSTANT, K=         .103E+02
IX (ABOUT INPUT AXIS)=         .445E+01          Y= 0.
IY (ABOUT INPUT AXIS)=         .110E+02          X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 2

ELEMENT NUMBERS: 16
17
18
19
20

DESCRIPTION: Base channel 2
5 x 2.75, 0.19 web, 0.32 flange, Al 6061-T6



PROPERTY NUMBER: 2 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.785	2.5
D	1.785	-2.5
E	-0.965	2.5
F	-0.965	-2.5

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
16,17,18,19,20	-2.50	0.59	0.0	-2.50	0.59	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.75)(0.32)}{2.59} = 0.68$$

$$K_2 = \frac{5(0.19)}{2.59} = 0.37$$

```
                              INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 2

INPUT
TYPE  DUM     B          H          B1         H1         X          Y          ALF
RECT 0.00  5.00000    2.75000    0.00000    0.00000    0.00000    0.00000    0.00000
RECT-1.00  4.36000    2.56000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
NO.    AREA        XC         YC         IX        IY         IXY        K
 1 13.75000    0.00000    1.37500    8.66536  28.64583   0.00000  34.66146
 2-11.16160    0.00000    1.47000   -6.09572 -17.68146   0.00000 -24.38289
```

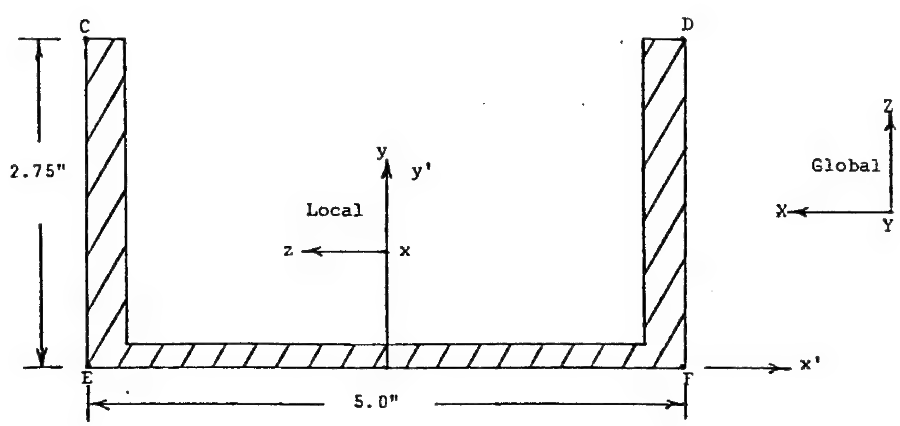
```
TOTAL AREA=                     .259E+01
X CENTROID DISTANCE=           0.
Y CENTROID DISTANCE=            .965E+00
IX (ABOUT CENTROID)=            .203E+01
IY (ABOUT CENTROID)=            .110E+02
IXY (ABOUT CENTROID)=          0.
IMAX=                           .110E+02
IMIN=                           .203E+01
ALPHA=                         -.180E+03
TORSIONAL CONSTANT, K=          .103E+02
IX (ABOUT INPUT AXIS)=          .445E+01            Y= 0.
IY (ABOUT INPUT AXIS)=          .110E+02            X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 2

ELEMENT NUMBERS:

21
23
24
25
26
27
28
29

DESCRIPTION: Vertical channel 2 at the back
5 x 2.75, 0.19 web, 0.32 flange, Al 6061-T6



PROPERTY NUMBER: 2 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.785	2.5
D	1.785	-2.5
E	-0.965	2.5
F	-0.965	-2.5

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
21	-2.50	-0.38	0.965	0.0	0.0	0.0
23	0.0	0.0	0.0	-2.50	0.0	0.965
24	-2.50	0.0	0.965	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.965
26	0.0	0.0	0.965	0.0	0.0	0.0
27	0.0	0.0	0.0	-2.50	0.0	0.965
28	-2.50	0.0	0.965	-2.50	0.0	0.965
29	-2.50	0.0	0.965	-2.50	0.38	0.965

SHEAR FACTORS

$$K_1 = \frac{2(2.75)(0.32)}{2.59} = 0.68$$

$$K_2 = \frac{5(0.19)}{2.59} = 0.37$$

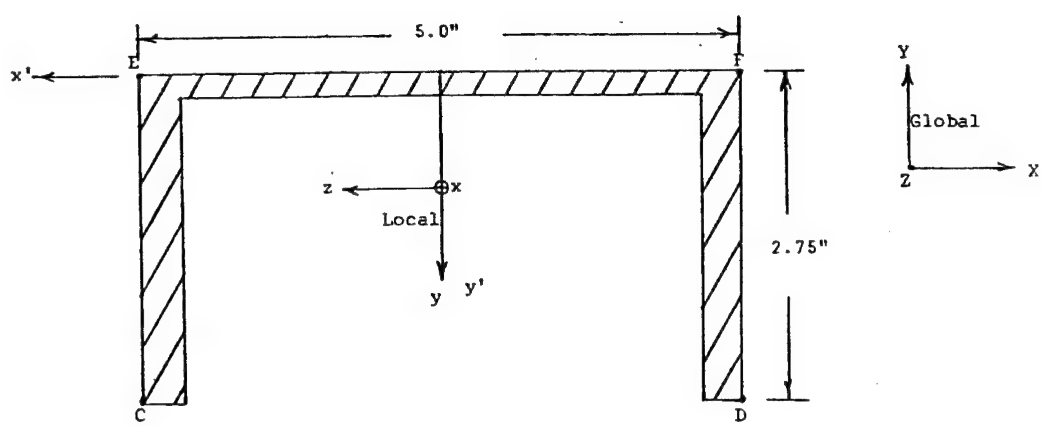
```
INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 2

INPUT
 TYPE   DUM      B          H          B1         H1         X          Y         ALF
 RECT  0.00   5.00000    2.75000    0.00000    0.00000    0.00000    0.00000    0.00000
 RECT -1.00   4.36000    2.56000    0.00000    0.00000    0.00000     .19000    0.00000

OUTPUT
 NO.     AREA        XC          YC          IX         IY           IXY          K
  1  13.75000    0.00000    1.37500    8.66536   28.64583    0.00000   34.60146
  2 -11.16160    0.00000    1.47000   -6.09572  -17.68146    0.00000  -24.58289
```

```
TOTAL AREA=                      .259E+01
X CENTROID DISTANCE=            0.
Y CENTROID DISTANCE=             .965E+00
IX (ABOUT CENTROID)=             .203E+01
IY (ABOUT CENTROID)=             .110E+02
IXY (ABOUT CENTROID)=           0.
IMAX=                            .110E+02
IMIN=                            .203E+01
ALPHA=                          -.180E+03
TORSIONAL CONSTANT, K=           .103E+02
IX (ABOUT INPUT AXIS)=           .445E+01            Y= 0.
IY (ABOUT INPUT AXIS)=           .110E+02            X= 0.
IXY (ABOUT INPUT AXIS)=         0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 2

ELEMENT NUMBERS: 30
31
32
62
63

DESCRIPTION: Top channel 2,
5 x 2.75, 0.19 web, 0.32 flange, Al 6061-T6



PROPERTY NUMBER: 2 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.785	2.5
D	1.785	-2.5
E	-0.965	2.5
F	-0.965	-2.5

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
30,31,32,62,63	-2.50	-0.59	0.0	-2.50	-0.59	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.75)(0.32)}{2.59} = 0.68$$

$$K_2 = \frac{5(0.19)}{2.59} = 0.37$$

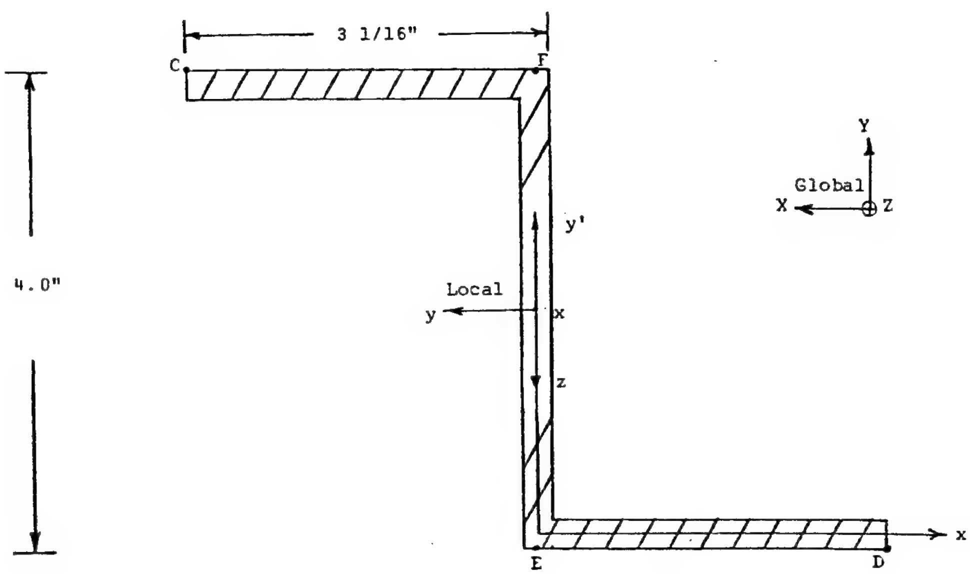
```
INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 2

INPUT
 TYPE   DUM       B          H          B1         H1         X          Y          ALF
 RECT 0.00  5.00000   2.75000   0.00000   0.00000   0.00000   0.00000   0.00000
 RECT-1.00  4.36000   2.56000   0.00000   0.00000   0.00000    .19000   0.00000

OUTPUT
 NO.     AREA        XC         YC         IX        IY         IXY         K
  1 13.75000   0.00000   1.37500   6.66536  28.64583   0.00000  34.66146
  2-11.16160   0.00000   1.47000  -6.04572 -17.66146   0.00000 -24.36269
```

```
TOTAL AREA=                   .259E+01
X CENTROID DISTANCE=         0.
Y CENTROID DISTANCE=          .965E+00
IX (ABOUT CENTROID)=          .203E+01
IY (ABOUT CENTROID)=          .110E+02
IXY (ABOUT CENTROID)=        0.
IMAX=                         .110E+02
IMIN=                         .203E+01
ALPHA=                       -.180E+03
TORSIONAL CONSTANT, K=        .103E+02
IX (ABOUT INPUT AXIS)=        .445E+01          Y= 0.
IY (ABOUT INPUT AXIS)=        .110E+02          X= 0.
IXY (ABOUT INPUT AXIS)=  0.

TORSIONAL CONSTANT BASED ON SUM
      NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 3

ELEMENT NUMBERS: 58
59
60
61

DESCRIPTION: Structural zee member
4 x 3 1/16, 1/4, Al 6061-T6



PROPERTY NUMBER: 3 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	2.938	-2.0
D	-2.938	2.0
E	0.0	2.0
F	0.0	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
58	0.0	-4.0	0.0	1.53	2.0	0.0
59	1.53	2.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	1.53	2.0	0.0
61	1.53	2.0	0.0	0.0	-4.0	0.0

SHEAR FACTORS

$$K_1 = \frac{2(3.063)(0.25)}{2.41} = 0.635$$

$$K_2 = \frac{4(0.25)}{2.41} = 0.415$$

INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 3

INPUT

TYPE	DUM	B	H	B1	H1	X	Y	ALF
RECT	0.00	5.87500	4.00000	0.00000	0.00000	0.00000	0.00000	0.00000
RECT	-1.00	3.75000	2.81250	0.00000	0.00000	2.93750	2.12500	90.00000
RECT	-1.00	3.75000	2.81250	0.00000	0.00000	-.12500	1.87500	90.00000

OUTPUT

NO.	AREA	XC	YC	IX	IY	IXY	K
1	23.50000	0.00000	2.00000	31.33333	67.54310	0.00000	125.33333
2	-10.54688	1.53125	2.12501	-12.35962	-6.95229	.00005	-27.80914
3	-10.54688	-1.53125	1.87501	-12.35962	-6.95229	.00005	-27.80914

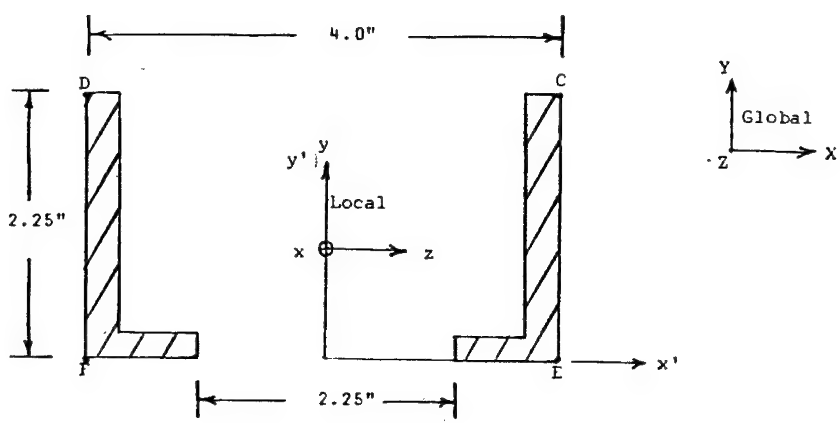
TOTAL AREA=	.241E+01		
X CENTROID DISTANCE=	-.427E-09		
Y CENTROID DISTANCE=	.200E+01		
IX (ABOUT CENTROID)=	.628E+01		
IY (ABOUT CENTROID)=	.423E+01		
IXY (ABOUT CENTROID)=	-.404E+01		
IMAX=	.942E+01		
IMIN=	.109E+01		
ALPHA=	.379E+02		
TORSIONAL CONSTANT, K=	.697E+02		
IX (ABOUT INPUT AXIS)=	.159E+02	Y=	0.
IY (ABOUT INPUT AXIS)=	.423E+01	X=	0.
IXY (ABOUT INPUT AXIS)=	-.404E+01		

TORSIONAL CONSTANT BASED ON SUM
NOT NECESSARILY ACCURATE

PROPERTY NUMBER: 4

ELEMENT NUMBERS: 37
40

DESCRIPTION: Upper console support channel 5 at isolator attachment 0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 4 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.275	2.0
D	1.275	-2.0
E	-0.975	2.0
F	-0.975	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
37,40	0.0	0.783	0.0	0.0	0.783	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.53} = 0.853$$

$$K_2 = \frac{1.75(0.19)}{1.53} = 0.217$$

INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 4

INPUT

TYPE	DUM	B	H	B1	H1	X	Y	ALF
RECT	0.00	4.00000	2.25000	0.00000	0.00000	0.00000	0.00000	0.00000
RECT	-1.00	3.42000	2.06000	0.00000	0.00000	0.00000	.19000	0.00000
RECT	-1.00	2.25000	.19000	0.00000	0.00000	0.00000	0.00000	0.00000

OUTPUT

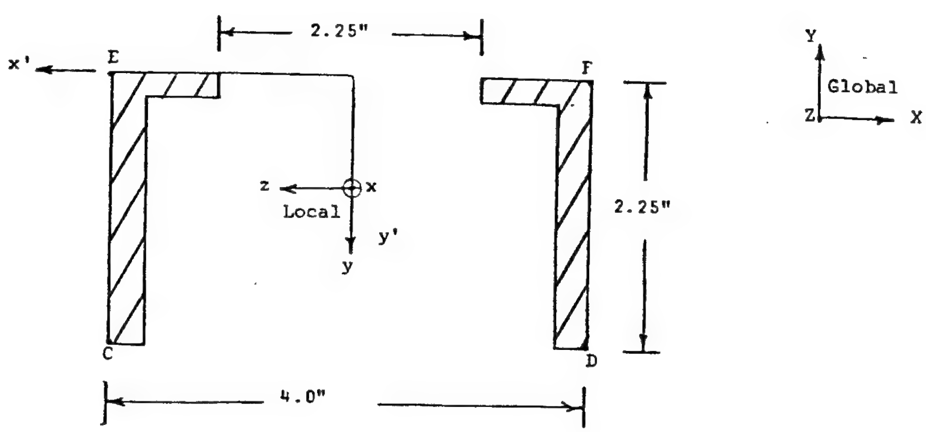
NO.	AREA	XC	YC	IX	IY	IXY	K
1	9.00000	0.00000	1.12500	3.79688	12.00000	0.00000	15.16750
2	-7.04520	0.00000	1.22000	-2.49142	-6.86696	0.00000	-9.96567
3	-.42750	0.00000	.09500	-.00129	-.18035	0.00000	-.00514

```
TOTAL AREA=                  .153E+01
X CENTROID DISTANCE=        0.
Y CENTROID DISTANCE=         .975E+00
IX (ABOUT CENTROID)=         .753E+00
IY (ABOUT CENTROID)=         .495E+01
IXY (ABOUT CENTROID)=       0.
IMAX=                        .495E+01
IMIN=                        .753E+00
ALPHA=                      -.180E+03
TORSIONAL CONSTANT, K=       .522E+01
IX (ABOUT INPUT AXIS)=       .220E+01          Y= 0.
IY (ABOUT INPUT AXIS)=       .495E+01          X= 0.
IXY (ABOUT INPUT AXIS)=     0.

TORSIONAL CONSTANT BASED ON SUM
        NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 4

ELEMENT NUMBERS: 43
46

DESCRIPTION: Lower console support channel 5 at isolators
0.19 web, 0.29 flange, Al 6061-T6



PROPERTY NUMBER: 4 (continued)

CALCULATIONS:

See INERTIA program output on following page.

STRESS RECOVERY POINTS

Point	y	z
C	1.275	2.0
D	1.275	-2.0
E	-0.975	2.0
F	-0.975	-2.0

OFFSET

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
43, 46	0.0	-0.783	0.0	0.0	-0.783	0.0

SHEAR FACTORS

$$K_1 = \frac{2(2.25)(0.29)}{1.53} = 0.853$$

$$K_2 = \frac{1.75(0.19)}{1.53} = 0.217$$

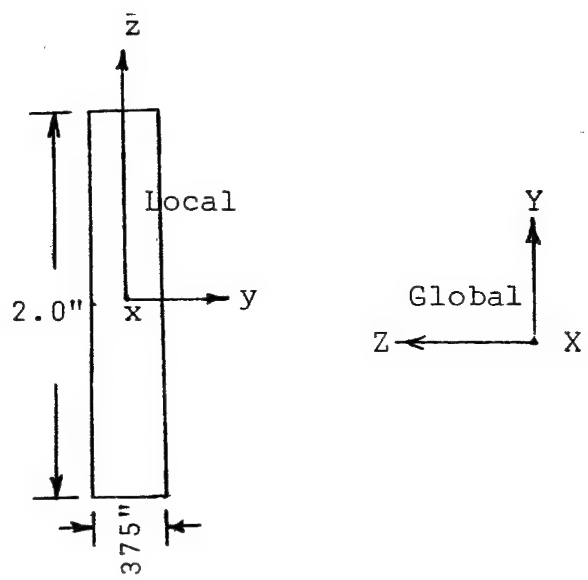
```
                                   INERTIA

BAR PROPERTY NUMBER
DESCRIPTION- PBAR NO. 4

INPUT
 TYPE  DUM       B          H          B1         H1         X          Y          ALF
 RECT 0.00   4.00000    2.25000    0.00000    0.00000    0.00000    0.00000    0.00000
 RECT-1.00   3.42000    2.06000    0.00000    0.00000    0.00000     .19000    0.00000
 RECT-1.00   2.25000     .19000    0.00000    0.00000    0.00000    0.00000    0.00000

OUTPUT
 NO.    AREA         XL         YL          IX         IY          IXY        K
  1   9.00000    0.00000    1.12500    3.79688   12.00000    0.00000   15.18750
  2  -7.04520    0.00000    1.22000   -2.49142   -6.86696    0.00000   -9.96567
  3   -.42750    0.00000     .09500    -.00129    -.16035    0.00000    -.00514
```

```
TOTAL AREA=                   .153E+01
X CENTROID DISTANCE=      0.
Y CENTROID DISTANCE=          .975E+00
IX (ABOUT CENTROID)=          .753E+00
IY (ABOUT CENTROID)=          .495E+01
IXY (ABOUT CENTROID)=     0.
IMAX=                         .495E+01
IMIN=                         .753E+00
ALPHA=                       -.180E+03
TORSIONAL CONSTANT, K=        .522E+01
IX (ABOUT INPUT AXIS)=        .220E+01           Y= 0.
IY (ABOUT INPUT AXIS)=        .495E+01           X= 0.
IXY (ABOUT INPUT AXIS)=   0.

TORSIONAL CONSTANT BASED ON SUM
       NOT NECESSARILY ACCURATE
```

PROPERTY NUMBER: 5

ELEMENT NUMBERS: 70
71
74
75

DESCRIPTION: Gusset stiffeners for channel 5 connection at upper corners



PROPERTY NUMBER: 5 (continued)

CALCULATIONS:

$$I_1 = \frac{(0.375)(2.0)^3}{12} = 0.25 \text{ in}^4$$

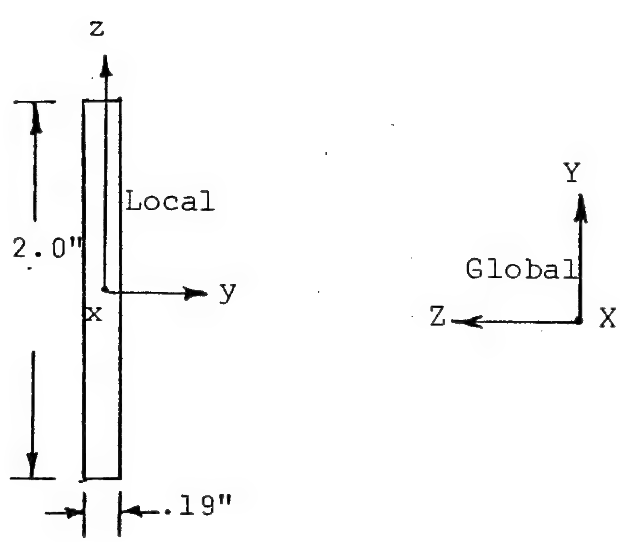
$$I_2 = \frac{(2.0)(0.375)^3}{12} = 0.009 \text{ in}^4$$

CBAR Element No.	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B
70,71,74,75	0.0	0.0	0.0	0.0	0.0	0.0

PROPERTY NUMBER: 6

ELEMENT NUMBERS: 65
66

DESCRIPTION: Effective cross section for connection of channel 3 to channel 2 at the top



PROPERTY NUMBER: 6 (continued)

CALCULATIONS:

$$A = (2.0)(0.19) = 0.38 \text{ in}^2$$

$$I_1 \quad \frac{(2.0)(0.19)^3}{12} = 0.001 \text{ in}^4$$

$$I_2 = \frac{(0.19)(2.0)^3}{12} = 0.127 \text{ in}^4$$

$$J = (0.19)^3(2/3) + 2.25(0.29)^3(2/3) = 0.041 \text{ in}^4$$

CBAR Element No.	Z1A	Z3A	Z3A	Z1B	Z2B	Z3B
65,66	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX C

DETAILED CALCULATIONS AND STRESS ANALYSIS

TABLE OF CONTENTS

C.1 WELDMENT STRESS CALCULATIONS

Those weldment areas on the support structure considered most critical will be analyzed in detail. There are two types of welds present - single bevel butt weld and $\frac{1}{4}$ in. leg fillet weld. Since most of the welds are the fillet type, it can be assumed that the following analysis addresses these unless indicated otherwise.

The absolute values of the element forces (bending moment, twist moment, and shear) are summed for the 1.5 g Side to Side, 9.0 g Fore, and 6 g Down loading conditions. This summation will yield the maximum internal loads imposed on the welds. Although the forces are an average for the CQUAD2 and CTRIA2 elements, a summation of the absolute values should guarantee conservative results. The NASTRAN force results of the plate elements are per unit length (i.e., force resultants).

C.1.1 LOWER CORNER WELD STRESSES

The first weld area analyzed is for the lower corner at which three channel members are welded together. Figure 5 shows the NASTRAN elements for this area. The NASTRAN force output for elements CQUAD2 193 and 196 gives the loading imposed on the weld between channel 5 and channel 2.

For CQUAD2 193,

$$M = 0.89 + 5.45 + 6.75 = 13.09 \text{ in-lb/in.}$$

$$T = 1.26 + 1.31 + 1.77 = 4.34 \text{ in-lb/in.}$$

$$V = 2.43 + 26.9 + 18.02 = 47.35 \text{ lb/in.}$$

For CQUAD2 196,

$$M = 0.63 + 3.03 + 2.69 = 6.35 \text{ in-lb/in.}$$

$$T = 0.17 + 5.36 + 1.04 = 6.57 \text{ in-lb/in.}$$

$$V = 2.86 + 6.45 + 14.42 = 23.73 \text{ lb/in.}$$

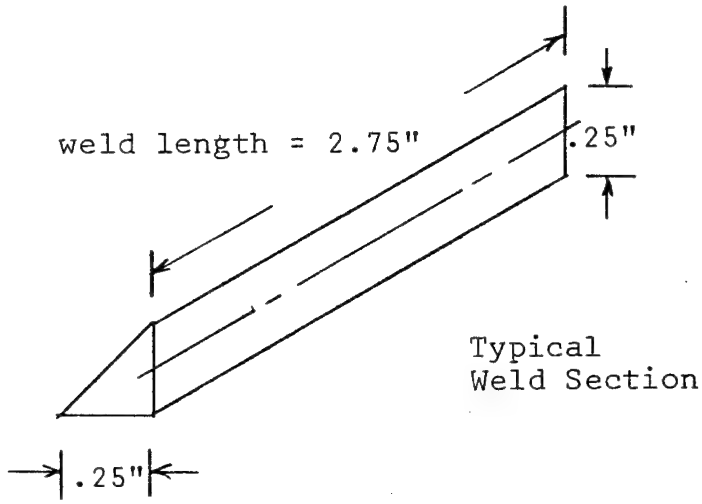
The force resultants for the two elements becomes,

$$M = 13.09 + 6.35 = 19.44 \text{ in-lb/in.}$$

$$T = \sqrt{(4.34)^2 + (6.57)^2} = 7.87 \text{ in-lb/in.}$$

$$V = 47.35 + 23.73 = 71.08 \text{ lb/in.}$$

Each of the above forces are per unit length and must be multiplied by the weld length to obtain the total force.



The moment of inertia for the weld between channel 5 and channel 2 is

$$I = \frac{(2.75)(0.25)^3}{12} = 0.0036 \text{ in.}^4$$

The bending stress is calculated as

$$\sigma = \frac{Mc}{I} = \frac{(19.44)(2.75)(0.125)}{0.0036} = 1856 \text{ psi.}$$

The shear stress due to the twisting moment is calculated as

$$\tau = \frac{T}{\ell t^2}\left(3 + 1.8\,\frac{t}{\ell}\right)$$ (from <u>Mechanical Engineering Design</u>, 2nd Edition, 1972, p. 69)

where ℓ = the weld length, t = the weld leg

$$\tau = \frac{(7.87)(2.75)}{(2.75)(0.25)^2}\left(3 + 1.8\,\frac{0.25}{2.75}\right) = 398 \text{ psi.}$$

The primary shear stress due to the shear force is calculated as

$$\tau = \frac{V}{A} \qquad \text{where A = area at the weld throat}$$

$$\tau = \frac{(71.08)(2.75)}{(0.707)(0.25)(2.75)} = 402$$

The total shear stress becomes

$$\tau = 402 + 398 = 800 \text{ psi.}$$

Thus, the maximum weld stresses become

$$\sigma_{max} = \frac{1856}{2} \quad \sqrt{\frac{(1856)^2}{4} + (800)^2} = 2153 \text{ psi.}$$

$$\tau_{max} = \sqrt{\frac{(1856)^2}{4} + (800)^2} = 1225 \text{ psi.}$$

The margins of safety are

$$MS = \frac{19,300}{2,153} - 1 = 8$$

$$MS = \frac{18,240}{1,225} - 1 = 14$$

Next the weld stresses between channel 5 and the gusset plate are analyzed. The NASTRAN forces in the element X coordinate of CQUAD2 196 depict the loads for this weld.

$$M = 0.63 + 3.03 + 2.69 = 6.35 \text{ in-lb/in.}$$

$$T = 0.17 + 5.36 + 1.04 = 6.57 \text{ in-lb/in.}$$

$$V = 2.86 + 6.45 + 14.42 = 23.73 \text{ lb/in.}$$

The moment of inertia for this weld is calculated as:

$$I = \frac{2(0.25)^3}{12} = 0.0026 \text{ in.}^4$$

The bending stress is

$$\sigma = \frac{(6.35)(2.0)(0.125)}{0.0026} = 611 \text{ psi.}$$

The twisting shear is

$$\tau = \frac{(6.57)(2.0)}{(2.0)(0.25)^2} \left(3 + 1.8 \frac{0.25}{2.0}\right) = 339 \text{ psi.}$$

The primary shear is

$$\tau = \frac{(23.73)(2.0)}{(0.707)(2.0)(0.25)} = 134 \text{ psi.}$$

The maximum stresses for this weld are calculated as

$$\sigma_{max} = \frac{611}{2} + \sqrt{\frac{(611)^2}{4} + (339 + 134)^2} = 869 \text{ psi.}$$

$$\tau_{max} = \sqrt{\frac{(611)^2}{4} + (339 + 134)^2} = 563 \text{ psi.}$$

Also, the margins of safety are

$$MS = \frac{19,300}{869} - 1 = 21$$

$$MS = \frac{18,240}{563} - 1 = 31$$

The maximum weld stresses between channel 5 and channel 3 are evaluated as follows. The highest forces occurred in element CQUAD2 192 and for the combined loading conditions yielded the following forces on the weld,

$$M = 1.15 + 8.66 + 5.11 = 14.92 \text{ in-lb/in.}$$
$$T = 0.78 + 5.40 + 0.28 = 6.46 \text{ in-lb/in.}$$
$$V = 2.77 + 75.11 + 7.98 = 85.86 \text{ lb/in.}$$

The moment of inertia for the weld about the element X-axis is

$$I = \frac{(2.25)(0.25)^3}{12} = 0.0029 \text{ in.}^4$$

Thus the bending stress is

$$\sigma = \frac{(14.92)(2.25)(0.125)}{0.0029} = 1447 \text{ psi.}$$

The shear stress due to the twisting moment is

$$\tau = \frac{(6.46)(2.25)}{(2.25)(0.25)^2} \left(3 + 1.8 \frac{0.25}{2.25}\right) = 331 \text{ psi.}$$

The primary shear stress is

$$\tau = \frac{(85.86)(2.25)}{(0.707)(0.25)(2.25)} = 487 \text{ psi.}$$

Therefore, the maximum weld stresses are calculated to be

$$\sigma_{max} = \frac{1447}{2} + \sqrt{\frac{(1447)^2}{4} + (331 + 487)^2} = 1815 \text{ psi.}$$

$$\tau_{max} = \sqrt{\frac{(1447)^2}{4} + (331 + 486)^2} = 1092 \text{ psi.}$$

The margins of safety for these maximum stresses become

$$MS = \frac{19,300}{1815} - 1 = 10$$

$$MS = \frac{18,240}{1091} - 1 = 16$$

The maximum weld stresses between channel 3 and channel 2 are calculated using the NASTRAN force output for elements CQUAD2 190 and 191.

For CQUAD2 190,

$$M = 0.55 + 8.15 + 0.57 = 9.27 \text{ in-lb/in.}$$

$$T = 0.92 + 7.11 + 3.69 = 11.72 \text{ in-lb/in.}$$

$$V = 0.37 + 8.65 + 4.08 = 13.10 \text{ lb/in.}$$

For CQUAD2 191,

$$M = 2.28 + 6.71 + 10.98 = 19.97 \text{ in-lb/in.}$$

$$T = 0.40 + 7.35 + 1.28 = 9.03 \text{ in-lb/in.}$$

$$V = 5.88 + 13.34 + 28.89 = 48.11 \text{ lb/in.}$$

The moment of inertia for each of these welds is

$$I = \frac{(2.06)(0.25)^3}{12} = 0.0027 \text{ in.}^4$$

The bending and shear stresses for the weld on CQUAD2 190 are

$$\sigma = \frac{(9.27)(2.06)(0.125)}{0.0027} = 884 \text{ psi.}$$

$$\tau = \frac{(11.72)(2.06)}{(2.06)(0.25)^2} \left(3 + 1.8 \frac{0.25}{2.06}\right) = 604 \text{ psi.}$$

$$\tau = \frac{(13.10)(2.06)}{(0.707)(2.06)(0.25)} = 75 \text{ psi.}$$

The maximum stresses for this weld are

$$\sigma_{max} = \frac{884}{2} + \sqrt{\frac{(884)^2}{4} + (604 + 75)^2} = 1252 \text{ psi.}$$

$$\tau_{max} = \sqrt{\frac{(884)^2}{4} + (604 + 75)^2} = 810 \text{ psi.}$$

The margins of safety are

$$MS = \frac{19,300}{1,252} - 1 = 14$$

$$MS = \frac{18,240}{810} - 1 = 22$$

The maximum stresses for the weld on CQUAD2 191 are

$$\sigma = \frac{(19.97)(2.06)(0.125)}{0.0027} = 1,905 \text{ psi.}$$

$$\tau = \frac{(9.03)(2.06)}{(2.06)(0.25)^2} (3 + 1.8 \frac{0.25}{2.06}) = 466 \text{ psi.}$$

$$\tau = \frac{(48.11)(2.06)}{(0.707)(2.06)(0.25)} = 272 \text{ psi.}$$

$$\sigma_{max} = \frac{1905}{2} + \sqrt{\frac{(1905)^2}{4} + (446 + 272)^2} = 2,145 \text{ psi.}$$

$$\tau_{max} = \sqrt{\frac{(1905)^2}{4} + (446 + 272)^2} = 1,193 \text{ psi.}$$

The margins of safety are

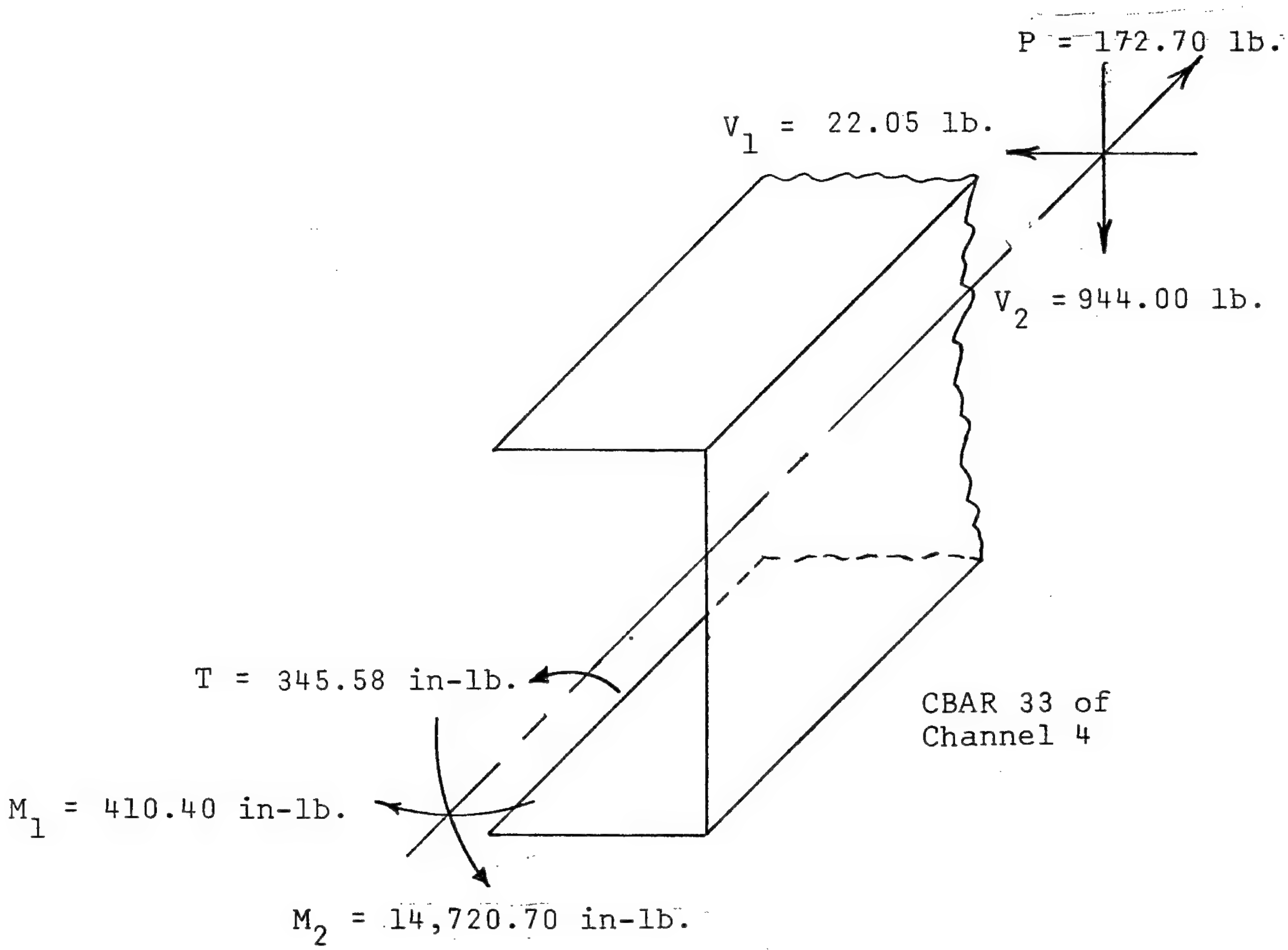
$$MS = \frac{19,300}{2,145} - 1 = 8$$

$$MS = \frac{18,240}{1,193} - 1 = 14$$

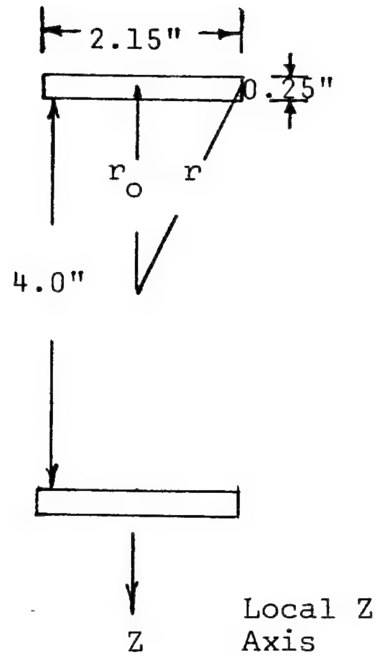
Since the NASTRAN output indicates small forces for the plate elements of the gussets, it is deemed unnecessary to analyze the welds on the gusset plates.

C.1.2 CROSS BRACE WELD STRESSES

Next the maximum weld stresses between channel 4 and channel 2 are calculated. The highest combined loads were obtained from the NASTRAN force output for element CBAR 33. The location of this element is shown in Figure 9.



The weldment moment of inertia for the element reference plane 2 is



$$J = A\left(\frac{\ell^2}{12} + r_o^2\right) = 2(0.38\ \text{in}^2)\left(\frac{(2.15)^2}{12} + (2.125)^2\right)$$

(from Mechanical Engineering Design, 2nd Edition, 1972, p. 69)

$$J = 3.72\ \text{in.}^4$$

For the secondary shear stress in plane 2

$$\tau = \frac{Mr}{J}$$

$$\tau = \frac{(14{,}720.70)(2.38)}{3.72} = 9{,}418\ \text{psi.}$$

And for the primary shear stresses in plane 2

$$\tau = \frac{V}{A} = \frac{944}{2(0.38)} = 1{,}242\ \text{psi.}$$

$$\tau = \frac{172.70}{2(0.38)} = 227\ \text{psi.}$$

The resultant shear stress becomes

$$\tau = \sqrt{(9{,}418)^2 + (1{,}242 + 227)^2} = 9{,}532\ \text{psi.}$$

The weldment moment of inertia for the element reference plane 1 is

$$I_z = \frac{2(2.15)^3(0.25)}{12} = 0.41 \text{ in.}^4$$

The weld stresses in plane 1 are

$$\sigma = \frac{Mc}{I_z} = \frac{(410.40)(1.08)}{0.41} = 1{,}081 \text{ psi.}$$

$$\tau = \frac{22.05}{2(0.707)(2.15)(0.25)} = 29 \text{ psi.}$$

The shear stress in plane 1 due to the axial torque is

$$J = 2r_o^2 A = 2(2.125)^2(0.38) = 3.43 \text{ in.}^4$$

$$\tau = \frac{(345.58)(2.125)}{3.43} = 214 \text{ psi.}$$

The resultant shear stress of planes 1 and 2 becomes

$$\tau = \sqrt{(9{,}538)^2 + (29 + 214)^2} = 9{,}541 \text{ psi.}$$

Thus, the maximum stresses for this weld are calculated to be

$$\sigma_{max} = \frac{1081}{2} + \sqrt{\frac{(1081)^2}{4} + (9{,}541)^2} = 10{,}097 \text{ psi.}$$

$$\tau_{max} = \sqrt{\frac{(1081)^2}{4} + (9{,}541)^2} = 9{,}556 \text{ psi.}$$

Also, the margins of safety are calculated as

$$MS = \frac{19{,}300}{10{,}097} - 1 = 0.91$$

$$MS = \frac{18{,}240}{9{,}556} - 1 = 0.91$$

C.1.3 ZEE MEMBER WELD STRESSES

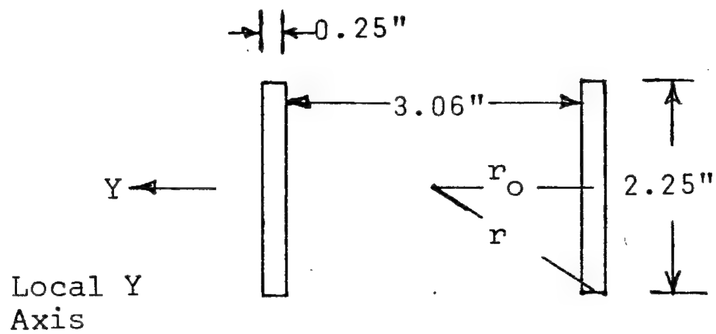
For the structural Zee at the base attachment, the maximum weld stresses to channel 3 are calculated. The highest forces of the Zee member occurred in element CBAR 61. This element is shown in Figure 10.

Forces for the 9 g loading condition in element reference plane 1,

$$M = 6{,}100.37$$
$$V = 3{,}768.24$$
$$T = 198.06$$

Forces for the 9 g loading condition in element reference plane 2,

$$M = 7{,}191.11$$
$$V = 4{,}839.42$$
$$P = 166.95$$



The weldment moment of inertia for bending in reference plane 1 of CBAR 61 is calculated as follows:

$$J = 2A\left(\frac{\ell^2}{12} + r_o^2\right) = 2(2.25)(0.707)(0.25)\left(\frac{(2.25)^2}{12} + (1.66)^2\right.$$

$$J = 2.53 \text{ in.}^4$$

The weld shear stresses in plane 1 are:

$$\tau = \frac{Mr}{J} = \frac{(6{,}100.37)(2.00)}{2.53} = 4{,}822 \text{ psi.}$$

$$\tau = \frac{(3{,}768.24)}{2(0.707)(2.25)(0.25)} = 4{,}738 \text{ psi.}$$

The shear stress due to the axial torque is calculated as

$$J' = 2r_o^2 A = 2(1.66)^2(0.707)(0.25)(2.25) = 2.19 \text{ in.}^4$$

$$\tau = \frac{T\, r_o}{J'} = \frac{(198.06)(1.66)}{2.19} = 150 \text{ psi.}$$

The resultant shear stress of plane 1 is,

$$\tau = \sqrt{(4{,}822)^2 + (4{,}738 + 150)^2} = 6{,}866 \text{ psi.}$$

The weldment moment of inertia for bending in reference plane 2 of CBAR 61 is calculated as follows

$$I_y = \frac{2(0.25)(2.25)^3}{12} = 0.47 \text{ in.}^4$$

The weld stresses in plane 2 are

$$\sigma = \frac{(7{,}191.11)(1.13)}{0.47} = 17{,}289 \text{ psi.}$$

$$\tau = \frac{(4{,}839.42)}{2(0.707)(0.25)(2.25)} = 6{,}084 \text{ psi.}$$

The shear stress in plane 2 due to the axial force

$$\tau = \frac{166.95}{2(0.707)(0.25)(2.25)} = 210 \text{ psi.}$$

The resultant shear stress for planes 1 and 2 becomes

$$\tau = \sqrt{(6{,}866)^2 + (6{,}084 + 210)^2} = 9{,}314 \text{ psi.}$$

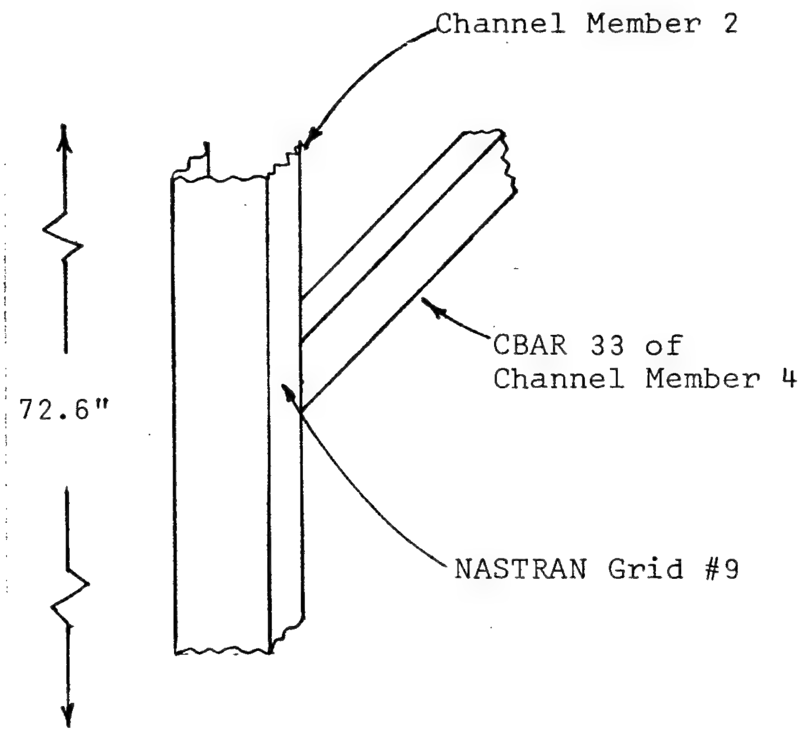
Therefore, the margins of safety for these weldment stresses are calculated as

$$MS = \frac{19{,}300}{17{,}289} - 1 = 0.12$$

$$MS = \frac{18{,}240}{9{,}314} - 1 = 0.96$$

C.2 BEAM COLUMN BUCKLING ANALYSIS

The vertical 5 in. channel members, channel 2, are analyzed for beam column stability, loaded according to the element forces from the NASTRAN output. A conservative analysis is made by assuming that the column is free at the top and fixed at the base. The length considered is 72.6 in.



The torsional effect of the cross brace channel 4 (CBAR 33) must also be included in the analysis. The torque imposed on the column by the cross brace will contribute to the beam column's instability. The critical buckling load is calculated by

$$P_{cr} = \frac{\pi^2 EI}{4\ell^2}$$ (from Mechanical Engineering Design, 2nd Edition, 1972, p. 138)

$$P_{cr} = \frac{\pi^2(10.4 \times 10^6)(11.0)}{4(72.6)^2} = 5.36 \times 10^4 \text{ lb.}$$

Since the highest axial loads for this member occurred in element CBAR 7, the element axial forces are combined for the 1.5 g Side to Side, 9.0 g Fore, and 6 g Down loading conditions.

$$P = 1,166.93 + 1,704.89 + 1,672.90 = 4,545 \text{ lb.}$$

In order to take into account the buckling moment induced in the column by channel 4, the axial torque of element CBAR 33 for the three loading conditions is divided by the translation in plane 1 of the attachment point between channel 2 and channel 4 (NASTRAN grid point 9). This method will provide an equivalent axial load to the column that has the same buckling effect on channel 2 as the torque from channel 4.

$$P_{eq} = \frac{88.49}{0.0046} + \frac{250.89}{0.430} + \frac{6.20}{0.0226} = 20,095 \text{ lb.}$$

Finally, the two axial loads can be combined to give the total vertical load on the column.

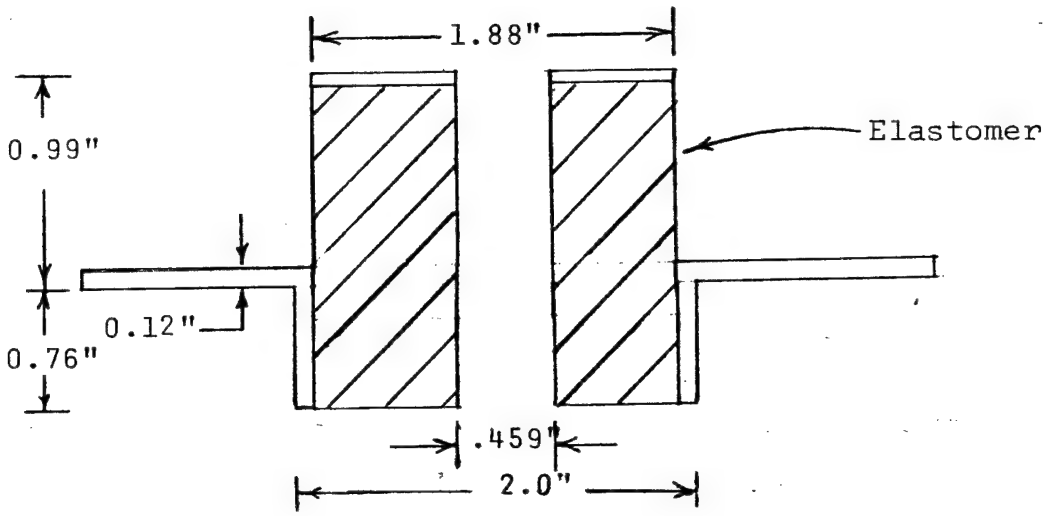
$$P_t = P + P_{eq} = 4,544 + 20,095 = 24,640 \text{ lb.}$$

The margin of safety is calculated as

$$MS = \frac{53,600}{24,640} - 1 = 1.2$$

C.3 ISOLATOR STRESS CALCULATIONS

The information received stated that the isolators were a Model 507 Code 3. Furthermore, the elastomer used in the isolators is given as natural rubber. The cross sectional dimensions of the isolator are as follows:



The area for tension, compression, and transverse shear is calculated to be

$$A = (1.88^2 - 0.459^2)\,\frac{\pi}{4} = 2.61 \text{ in.}^2$$

The bearing stress area is calculated to be

$$A_b = \frac{1}{2}(0.459)\,\pi(0.76 + 0.12) = 0.63 \text{ in.}^2$$

The combined maximum axial and shear loads on one isolator for the 1.5 g Side to Side, 9.0 g Fore, and 6 g Down loading conditions is obtained from Table 5.

$$P_y = (0.13) + (1.38) + 1{,}179.51) = 1{,}181.02 \text{ lb.}$$

$$P_{xz} = [(318.21)^2 + (18.45)^2 + (1{,}671.83)^2 + (96.38)^2 + (102.30)^2 + (51.24)^2]^{1/2} = 1{,}708.51 \text{ lb.}$$

The corresponding stresses are

$$\sigma = \frac{(1{,}181.02)}{2.16} = 453 \text{ psi.}$$

$$\tau = \frac{(1{,}708.51)}{2.61} = 655 \text{ psi.}$$

The bearing stress is calculated as,

$$\sigma_b = \frac{(1,708.51)}{0.63} = 2,712 \text{ psi.}$$

The tensile strength of natural rubber is 4,000 psi. This is from "Machine Design," Materials Reference Issue, March 1976, p. 196. No value was given for the compressive strength, but it should be conservative to use the tensile strength. Also, the shear strength is assumed to be 60% of the tensile strength. The margins of safety become

$$MS = \frac{4,000}{453} - 1 = 8$$

$$MS = \frac{2,400}{655} - 1 = 3$$

$$MS = \frac{4,000}{2,712} - 1 = 0.5$$

Also, a check is made for bottoming out of the isolators. From Table 6, the maximum relative displacements for the isolator are 0.87 in. in the transverse direction and 0.64 in. in the axial direction.

The clearance in the axial direction is

$$\delta_{ca} = 0.76 \text{ in.}$$

Consequently, the displacement is less than the clearance for the axial direction.

The clearance in the transverse direction is

$$\delta_{ct} = (2.0 - 0.459)/2 = 0.77 \text{ in.}$$

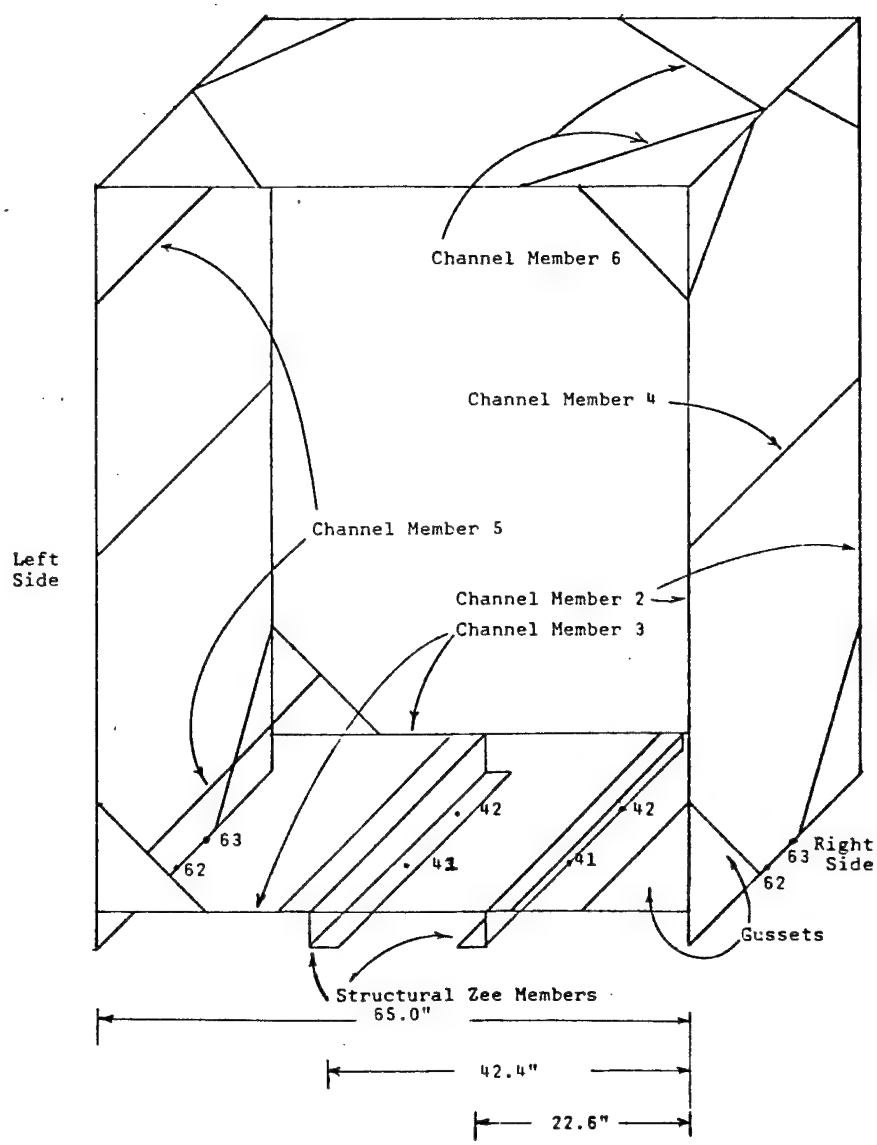
The relative displacement in the transverse direction is 0.10 in. greater than the clearance.

APPENDIX D

STATIC EQUILIBRIUM CALCULATIONS

This appendix supplies the calculations to verify static equilibrium for the entire support frame. Calculations are included for the balance of forces and moments for each of the six loading conditions. The reaction forces at the base attachment grid points (41, 42, 62, and 63) were obtained from the NASTRAN output of Forces of Single-Point Constraint and combined for the right and left halves. The summation of moments was taken at grid point 62 on the right side.

D.1 SUMMATION OF FORCES



Summation of Forces in the x Direction
1.5 g +z Side Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
238.1	-18.5	0
-238.8	18.5	
-56.6	-18.5	
55.4	18.5	
-345.4	-18.5	
346.2	18.5	
82.0	-18.5	
-80.8	18.5	
$\sum=$ 0.10	0	0

Summation of Forces in the x Direction
1.5 g +z Side Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
318.9	-0.13	0
-319.9	0.13	
2,210.8	-0.13	
-2,209.8	0.13	
459.1	-0.13	
-459.1	0.13	
2,547.1	-0.13	
-2,546.1	0.13	
$\sum=$ 1.0	0	0

Summation of Forces in the z Direction
1.5 g +z Side Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-121.7	225.5	1.5 (270.7) =
-117.3	225.5	406.1
-450.9	226.4	
-448.5	226.4	
-137.3	317.3	
-132.3	317.3	
-588.2	318.2	
-584.9	318.2	
$\sum$= -2,581.1	2,174.8	406.1

Summation of Forces in the x Direction
1.5 g -z Side Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-238.1	-18.5	0
238.8	18.5	
56.6	-18.5	
-55.4	18.5	
345.4	-18.5	
-346.2	18.5	
-82.0	-18.5	
80.8	18.5	
$\sum$= -0.10	0	0

Summation of Forces in the y Direction
1.5 g -z Side Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-318.9	-0.13	0
319.9	0.13	
-2,210.8	-0.13	
2,209.8	0.13	
-458.1	-0.13	
459.1	0.13	
-2,547.1	-0.13	
2,540.1	0.13	
$\sum =$ -6.0	0	0

Summation of Forces in the z Direction
1.5 g -z Side Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
121.7	-225.5	-1.5 g (270.7)=
117.3	-225.5	-406.1
450.9	-226.4	
448.5	-226.4	
137.3	-317.3	
132.3	-317.3	
588.2	-318.2	
584.9	-318.2	
$\sum =$ 2,581.1	-2,174.8	-406.1

Summation of Forces in the x Direction
9 g Fore Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-3,988.8	1,668.2	9(270.7) =
-3,760.8	1,590.7	2,436.3
20.5	1,668.2	
-14.1	1,590.7	
-3,988.8	1,671.8	
-3,760.8	1,594.4	
20.5	1,671.8	
-14.1	1,594.4	
$\sum$= -15,486.4	13,050.2	2,436.3

Summation of Forces in the y Direction
9 g Fore Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-5,083.4	1.4	0
-4,785.5	1.4	
6,406.5	-1.4	
7,076.3	-1.4	
5,083.4	1.4	
4,785.5	1.4	
-6,406.5	-1.4	
-7,076.3	-1.4	
$\sum$= 0	0	0

Summation of Forces in the z Direction
9 g Fore Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-5,883.2	-96.4	0
5,924.2	-96.4	
1,622.2	96.4	
-1,345.1	96.4	
5,883.2	-96.4	
-5,924.2	-96.4	
-1,622.2	96.4	
1,345.1	96.4	
$\sum =$ 0	0	0

Summation of Forces in the x Direction
1.5 g Aft Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
664.8	-278.0	-1.5(270.7) =
626.8	-265.1	-406.1
-3.4	-278.0	
2.4	-265.1	
664.8	-278.6	
626.8	-265.7	
-3.4	-278.6	
2.4	-265.7	
$\sum =$ 2,581.2	-2,174.8	-406.1

Summation of Forces in the y Direction
1.5 g Aft Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
847.2	-0.2	0
797.6	-0.2	
-1,067.8	0.2	
-1,179.4	0.2	
-847.2	-0.2	
-797.6	-0.2	
1,067.8	0.2	
1,179.4	0.2	
$\sum =$ 0	0	0

Summation of Forces in the z Direction
1.5 g Aft Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
980.5	16.1	0
-987.4	16.1	
-270.4	-16.1	
224.2	-16.1	
-980.5	16.1	
987.4	16.1	
270.4	-16.1	
-224.2	-16.1	
$\sum =$ 0	0	0

Summation of Forces in the x Direction
6 g Down Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
421.8	-102.3	0
354.5	-102.3	
-490.4	-102.3	
-475.8	-102.3	
-219.5	102.3	
-152.4	102.3	
289.1	102.3	
272.7	102.3	
∑= 0	0	0

Summation of Forces in the y Direction
6 g Down Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
550.4	-1,026.3	-6(270.7) =
462.3	-995.5	-1,624.2
2,156.9	-1,179.5	
1,505.2	-1,148.7	
288.6	-1,026.3	
200.9	-995.5	
2,907.5	-1,179.5	
2,752.6	-1,148.7	
∑= 10,324.4	-8,700.0	-1,624.2

Summation of Forces in the z Direction
6 g Down Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
520.5	51.2	0
-519.9	51.2	
639.1	51.2	
-639.7	51.2	
211.3	-51.2	
-209.9	-51.2	
701.3	-51.2	
-702.7	-51.2	
∑= 0	0	0

Summation of Forces in the x Direction
3 g Up Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-210.9	51.2	0
-177.3	51.2	
245.2	51.2	
237.9	51.2	
109.7	-51.2	
76.2	-51.2	
-144.5	-51.2	
-136.4	-51.2	
∑= -0.10	0	0

Summation of Forces in the y Direction
3 g Up Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-275.2	513.2	3(270.7) =
-231.2	497.7	812.1
-1,078.4	589.8	
-752.6	574.3	
-144.3	513.2	
-100.4	497.7	
-1,453.8	589.8	
-1,126.3	574.3	
$\sum$= -5,162.2	4,350.0	812.1

Summation of Forces in the z Direction
3 g Up Loading Condition

Attachment Reactions	Console Reactions	Gravity Frame Loading
-260.3	-25.6	0
259.9	-25.6	
-319.6	-25.6	
319.8	-25.6	
-105.6	25.6	
104.9	25.6	
-350.7	25.6	
351.4	25.6	
$\sum$= -0.20	0	0

D.2 SUMMATION OF MOMENTS

ΣM about the x axis for 1.5 g +z Side Loading.

-20.5(319.9) - 20.5(2209.8) - 20.5(459.1) - 20.5(2546.1)

- 20.5(0.13)4 + 78.4(225.5)2 + 78.4(317.3)2 + 10.25(226.4)2

+ 10.25(318.2)2 + 1.5(270.7)42.4 = 15.8

ΣM about the y axis for 1.5 g +z Side Loading.

20.5(238.8) - 20.5(55.4) - 20.5(346.2) + 20.5(80.8)

+ 20.5(18.5)4 - 22.6(121.7) - 22.6(117.3) - 42.4(137.3)

- 42.4(132.3) - 65(588.2) - 65(584.9) + 7(225.5)2

+ 7(226.4)2 + 58(317.3)2 + 58(318.2)2 + 1.5(270.7)32.5

= -6.72

ΣM about the z axis for 1.5 g +z Side Loading.

-20.5(318.9) + 20.5(319.9) - 42.4(459.1) + 42.4(459.1)

- 65(2,547.1) + 65(2,546.1) = -44.5

ΣM about the x axis for 1.5 g -z Side Loading.

20.5(319.9) + 20.5(2209.8) + 20.5(459.1) + 20.5(2,546.1)

+ 20.5(0.13)4 - 78.4(225.5)2 - 78.4(317.3)2 - 10.25(226.4)2

- 10.25(318.2)2 - 1.5(270.7)42.4 = -15.8

ΣM about the y axis for 1.5 g -z Side Loading.

-20.5(238.8) + 20.5(55.4) + 20.5(346.2) - 20.5(80.8)

- 20.5(18.5)4 + 22.6(121.7) + 22.6(117.3) + 42.4(137.3)

- 42.4(132.3) + 65(588.2) + 65(584.9) - 7(225.5)2

- 7(226.4)2 - 58(317.3)2 - 58(318.2)2 - 1.5(270.7)32.5

= 6.72

ΣM about the z axis for 1.5 g -z Side Loading.

20.5(318.9) - 20.5(319.9) + 42.4(459.1) - 42.4(459.1)

+ 65(2,547.1) - 65(2,546.1) = 44.5

ΣM about the x axis for 9 g Fore Loading.

-20.5(4,785.5) + 20.5(7,076.3) + 20.5(4,785.5)

- 20.5(7,076.3) = 0.0

ΣM about the y axis for 9 g Fore Loading.

20.5(3,760.8) + 20.5(14.1) + 20.5(3,760.8) + 20.5(14.1)

- 20.5(1,590.7)2 - 20.5(1,594.4)2 - 10.2(270.7)9

- 22.6(5,883.2) + 22.6(5,924.2) + 42.4(5,883.2)

- 42.4(5,924.2) - 65(1,622.2) + 65(1,345.1) - 7(96.4)4

+ 58(96.4)4 = 173.8

ΣM about the z axis for 9 g Fore Loading.

22.6(5,083.4) + 22.6(4,785.5) - 42.4(5,083.4) - 42.4(4,785.5)

+ 65(6,406.5) + 65(7,076.3) - 7(1.4)4 + 58(1.4)4

- 78.4(1,590.7)2 - 78.4(1,668.2)2 - 10.25(1,594.4)2

- 10.25(1,671.8)2 - 42.4(270.7)9 = 11.6

ΣM about the x axis for 1.5 g Aft Loading.

20.5(797.6) - 20.5(1,179.4) - 20.5(797.6)

+ 20.5(1,179.4) = 0.0

ΣM about the y axis for 1.5 g Aft Loading.

-20.5(626.8) - 20.5(2.4) - 20.5(626.8) - 20.5(2.4)

+ 22.6(980.5) - 22.6(987.4) - 42.4(980.5) + 42.4(987.4)

+ 65(270.4) - 65(224.2) + 20.5(265.3)4 + 7(16.1)

- 58(16.1)4 + 10.2(270.7)1.5 = -383.8

ΣM about the z axis for 1.5 g Aft Loading.

-22.6(847.2) - 22.6(797.6) + 42.4(847.2) + 42.4(797.6)

- 65(1,067.8) - 65(1,179.4) + 78.4(265.1)2 + 78.4(278.0)2

+ 10.25(265.7)2 + 10.25(278.6)2 + 7(0.2)4 - 58(0.2)4

+ 42.4(270.7)1.5 = -9.01

ΣM about the x axis for 6 g Down Loading.

20.5(462.3) + 20.5(200.9) + 20.5(2,252.6) - 20.5(1,148.7)2

- 20.5(995.5)2 + 78.4(51.2)4 - 10.2(51.2)4 - 10.2(270.7)6

+ 20.5(1,505.2) = 118.8

ΣM about the y axis for 6 g Down Loading.

-20.5(354.5) + 20.5(475.8) + 20.5(152.4) - 20.5(272.7)

+ 22.6(520.5) - 22.6(519.9) + 42.4(211.3) - 42.4(209.9)

+ 65(701.3) - 65(702.7) = -91.0

ΣM about the z axis for 6 g Down Loading.

-22.6(550.4) - 22.6(462.3) - 42.4(288.6) - 42.4(200.9)

- 65(2,907.5) - 65(2,252.6) + 32.5(270.7)6 + 7(1,026.3)2

+ 7(995.5)2 + 58(1,148.7)2 + 58(1,179.5)2 + 78.4(102.3)4

- 10.2(102.3)4 = 22.0

ΣM about the x axis for 3 g Up Loading.

-20.5(231.2) - 20.5(752.6) - 20.5(100.4) - 20.5(1,126.3)

+ 20.5(574.3)2 + 20.5(497.7)2 + 10.2(270.7)3 - 78.4(25.6)4

+ 10.2(25.6)4 = -63.5

ΣM about the y axis for 3 g Up Loading.

20.5(177.3) - 20.5(237.9) - 20.5(76.2) + 20.5(136.4)

- 22.6(260.3) + 22.6(259.9) - 42.4(105.6) + 42.4(104.9)

- 65(350.7) + 65(351.4) = -1.4

ΣM about the z axis for 3 g Up Loading.

$$22.6(275.2) + 22.6(231.2) + 42.4(144.3) + 42.4(100.4)$$
$$+ 65(1,453.8) + 65(1,126.3) - 32.5(270.7)3 - 58(589.8)2$$
$$- 58(574.3)2 - 7(513.2)2 - 7(497.7)2 - 78.4(51.2)4$$
$$+ 10.2(51.2)4 = -22.4$$